

# **THE MINDFUL UNIVERSE**

## **1. SCIENCE AND HUMAN VALUES.**

This book is about what you are, and how you are connected to what you are not. It is about the impact of the revolutionary developments in physics during the twentieth century upon science's idea of you as a thinking and acting entity, and your linkage to the rest of nature.

These questions might appear to belong more to philosophy, metaphysics, or religion, rather than to physics, which is usually assumed to deal only with such tangible items as machines, rockets, transistors, and atomic bombs. But the radical change in our understanding of the physical world that occurred during the twentieth century has transformed connections that formerly had been matters of philosophical speculation into issues covered by basic physical theory. The aim of this book is to explain the new idea of the nature of human beings, and their causal role in the unfolding of reality, to readers with no prior understanding of the quantum character of the world.

Science has improved our lives in many ways. It has lightened the load of tedious tasks and expanded our physical powers, and thereby contributed to a great flowering of human creative energy. On the other hand, it has also given us the capacity to ravage the environment on an unprecedented scale and obliterate our species altogether. Yet along with this fatal power it has provided a further offering which, though subtle in character and still hardly felt in the minds of men, may ultimately be its most valuable contribution to human civilization, and the key to human survival.

Science is not only the enterprise of harnessing nature to serve the practical needs of humankind. It is also part of man's unending search for knowledge about the

universe and his place within it. This quest is motivated not solely by idle curiosity. Each of us, when trying to establish values upon which to base conduct, is inevitably led to the question of one's place in the greater whole. The linkage of this philosophical inquiry to the practical question of personal values is no mere intellectual abstraction. Martyrs in every age are vivid reminders of the fact that no influence upon human conduct, even the instinct for self preservation, is stronger than beliefs about one's relationship to the power that shapes the universe. Such beliefs form the foundation of a person's self image, and hence, ultimately, of that person's values.

It is often claimed that science stands mute on questions of values: that science can help us to achieve what we value once our priorities are fixed, but can play no role in fixing these weightings. That claim is certainly incorrect: science plays a key role in these matters. For what we value depends on what we believe, and what we believe is increasingly determined by science.

A striking example of this influence is the impact of science upon the system of values promulgated by the church during the Middle Ages. That structure rested on a credo about the nature of the universe, its creator, and man's connection to that creator. Science, by casting doubt upon that belief, undermined the system of values erected upon it. Moreover, it put forth a credo of its own. In that "scientific" vision we human beings were converted from sparks of divine creative power, endowed with free will, to automatons---to cogs in a giant machine that grinds inexorably along a preordained path in the grip of a blind mechanical process.

Gone from this "scientific" picture of our species is any rational basis for the notion of a person's responsibility for his own actions. Each of us is asserted to be a mechanical extension of what existed prior to his birth. Over that earlier situation one has no control. Hence for

what emerges, preordained, from that prior state one can bear no responsibility.

Given this conception of man the collapse of moral philosophy is inevitable. For this notion of the human being provides no rational basis for any value but self interest: behavior promoting the welfare of others, including future generations, becomes rational only to the extent that such behavior serves one's own interests. Hence science becomes doubly culpable: it not only undermines the foundations of earlier value systems, but also strips man of any vision of himself and his place in the universe that could be the rational basis for any elevated set of values.

This mechanical view of nature and man's place within it dominated science at the end of the nineteenth century. According to that notion, the physical universe is composed of tiny bits of matter, and the unfolding of the observed world over the course of time is completely fixed by direct contact interactions between these localized microscopic elements. Human beings, insofar as they are parts of this physically describable reality, are simply conglomerations of these tiny components, whose motions are completely fixed at the microlevel.

During the twentieth-century this simple picture of nature was found to be profoundly wrong. It failed not just in its fine details, but at its fundamental core. A vastly different conceptual framework was erected by the atomic physicists Werner Heisenberg, Niels Bohr, Wolfgang Pauli and their colleagues. Those scientists were forced to a wholesale revision of the entire subject matter of physical theory by the strange character of the new mathematical rules, which were invariably validated by reliable empirical data.

The earlier "classical" physics arose from the study of motions of the planets and large terrestrial objects. Rules were found that, as far as we could detect, controlled the behavior of these entities in ways that

were completely independent of whether we were observing them or not. Those purported “laws of motion” were formulated in terms of simple properties that existed and evolved independently of their being observed by anyone. The “laws” governing their behavior took no special cognizance of the acts of observation performed upon them by human beings, or of the knowledge acquired from these observations. However, the baffling features of the data obtained during the twentieth century caused the physicists who were studying these phenomena, and were trying to ascertain the rules that governed them, to turn the whole scientific enterprise upside down, or perhaps I should say turned *what had been upside down* rightside up. The word “science” comes the latin “scire,” to know. So the quantum physicists said, basically, that the proper subject matter of science is not what may or may not be “out there,” unobserved and unknown, but is rather what we human beings know. Thus they formulated their new theory, called quantum theory, around the *knowledge acquiring activities* of human beings, and around the knowledge derived from these activities, rather than around some imagined-to-exist world out there. The whole emphasis and focus of the theory, at least from a philosophical perspective, was thus shifted from one that ignored us to one that was about us.

This shift did not amount merely to looking at the same old physical world from a different point of view. Rather the whole landscape was transformed into something so strange that it seemed to be understandable only in terms of how it worked for us.

The new conception of the physical world is vastly different from the old one in many interesting ways that have excited the interest of physicists. However, the revised understanding of the basic nature of human beings, and of their role in nature, is, I believe, the most interesting or exciting thing of all, and probably, in the final analysis, the most important.

The new theory, called quantum theory, accounts in a uniform manner for all the observed successes of the earlier physical theories, plus the immense accumulation of new data where the earlier methods fail abysmally. However, it describes a world built not out of bits of matter, as matter was understood in the nineteenth century, but rather out of a fundamentally different kind of stuff. According to the revised notion, physical reality behaves more like *spatially encoded information that governs tendencies for experiential events to occur*, than like anything resembling material substance.

Moreover, according to this new understanding, the natural world is governed not by one single uniform process, but by *two* very different processes, only one of which is analogous to the laws of classical physics. This quantum analog of the older classical process is the part of the new theory of main interest to physicists, engineers, and other workers *not* concerned with the mental side of reality. But anyone interested in the role in nature of our conscious thoughts, ideas, and feelings will want to understand the other process, because it specifies how our thoughts affect the dynamical evolution of the physical world.

Nothing like this “action-of-mind” process exists in classical physics. Indeed, there is nothing in the classical concepts or principles that requires such things as thought, ideas, and feeling to exist at all, and certainly no rule that dictates how the idea-like aspects of nature impact upon and change the physical aspects. Indeed, it has been precisely the absence of any notion of experiential-type realities in classical physics, or of any job for them to do, or of any possibility for them to do anything not already done by the tiny mechanical elements that has been the bane of philosophy for three hundred years. Now, however, the Newtonian-type

conception of nature that has been the basis of so much philosophical dispute has been found to be fundamentally false, and has been replaced by a radically different idea that reproduces all the verified results of the prior theory, and also correctly accounts for the huge wealth of new data, and moreover put thoughts, ideas, and feelings into the driver's seat. The new theory, unlike the old one, rests upon a *causally potent us*, described as we intuitively understand ourselves.

The original formulation of quantum theory was created by physicists gather around Niels Bohr, at his institution in Copenhagen, and is called the Copenhagen interpretation. It remains the official doctrine, and is what is always used in practice. However, it is formulated as a set of rules to be used by physicists as they go about their jobs of collecting data and making predictions. But the eminent mathematician John von Neumann created an enveloping theory christened "The Orthodox Interpretation" by his friend and colleague, the Nobel Laureate Eugene Wigner. Von Neumann's formulation puts the mental and physical aspects of nature on a more equal footing, and can be regarded as an ontology: that is, as a theory of nature herself.

Von Neumann's quantum theory is built on *two* processes, Process I and Process II. The latter is the quantum mechanical analog of the classical process that generates motions in accordance with the Classical Laws of Motion," and like its classical cousin is local and deterministic: Process II is "local" in the sense that it is controlled completely by "contact" interactions between immediate neighbors, with no effect propagating faster than the speed of light, and is "deterministic" in that when acting alone, with no intervention of Process I, it carries the state of the physical universe from an earlier time to a later time in a completely determined and unambiguous way.

Process I, on the other hand, is the “action-of-mind” process. It describes the *causal influence of conscious agents upon the physical world*.

The existence of this dynamical effect of conscious experience upon the course of physical events is inimical to the precepts that had ruled science during the eighteenth and nineteenth centuries, and that had become nearly synonymous with the idea of what science is. Accordingly, some quantum physicists want to replace the Orthodox/Copenhagen conception, and have worked assiduously to eradicate this contamination of physics by psychology, on the grounds that it injects subjective elements in a fundamental way into a discipline that they believe should be fully objective. However, in spite of intensive efforts, no rationally coherent way has been found to obtain the predictions of quantum theory without using von Neumann’s Process I, or something that stands in its place and does its job. Accordingly, I shall accept here the orthodox quantum theory of von Neumann and its logical developments. Lacunae in the alternative proposals are described in chapter 9.

This revised conception of the causal connection between your thoughts and your actions amounts to a new understanding of your intrinsic nature. However, widespread awareness of this revised conception of the human person has been effectively excluded from the minds of most non-physicists by the focus of popular accounts of quantum theory on features more interesting to physicists, namely the occurrence of a statistical or random element, and an apparent breakdown of the locality idea that no influence can propagate faster than light. Those features are important parts of the full story. But Process I is something else. It injects into the dynamical process choices that are “free,” in the very specific sense that they *not controlled by any yet-known law or rule of nature*, statistical or otherwise, and yet can significantly influence the course of physical events. In orthodox

quantum theory these free choices are made by human beings. Thus, according to orthodox contemporary physics, as formulated either by the founders or by von Neumann, your physical actions are in principle determined in part by conscious choices that *are not governed by any yet-known law of nature*. This means that your thoughts, ideas, and feelings can, *by virtue of the basic laws of physics*, influence your actions, without being themselves controlled by any yet-discovered law.

Von Neumann's formulation not only *accommodates* this causal linkage: it also explains *how* it works---or at least how it *can* work. It also explains *why* this influence of mind upon brain vanishes when one makes the "classical approximation," which eliminates all quantum effects and reduces the quantum laws to corresponding classical ones.

You might now say: So what's new? I always knew my thoughts influenced my actions!

You may indeed have always known this. Your knowledge that your mental efforts can affect your bodily behavior is something you learned in the first few months after birth, and is fundamental to your dealings with the world. However, that seemingly obvious truth is incompatible with the verdict of science that prevailed from the time of Isaac Newton until 1900. That enduring conflict produced three hundred years of philosophical turmoil, which has spilt over into the political, social, legal, educational, and moral arenas, and deeply affected the intellectual climate in which you are imbedded, and thereby inevitably influenced also your conception of yourself as part of the culturally defined universe.

Philosophers tried relentlessly for three centuries to understand the role of mind in the workings of a brain conceived to function according to principles of classical physics. We now know no such brain actually exists: no brain, body, or anything else in the real world is

composed of those tiny bits of matter that Newton imagined the universe to be made of. Hence it is hardly surprising that those philosophical endeavors were beset by enormous difficulties, which led to such positions as that of the 'eliminative materialists', who hold that our conscious thoughts do not exist; or of the 'epiphenomenalists', who admit that human experiences do exist but claim that they play absolutely no role in how we behave; or of the 'identity theorists', who claim that each conscious feeling is exactly the same thing as a motion of the particles that nineteenth century science thought brains and everything else in the universe to be made of, but that we now know do not exist, at least as they were formerly conceived. The tremendous difficulty in reconciling causally efficacious thought with the older physics is dramatized by the fact that for many years the mere mention of "consciousness" was considered evidence of backwardness and bad taste in most of academia, including, incredibly, even the philosophy of mind.

What exactly is this conflict between classical physics and the conviction of most of us that our thoughts and mental efforts make a difference in how we behave? The problem was apparent already at the time of Newton. But during the second half of the twentieth century it has been buried under an avalanche of philosophical argumentation and counter-argumentation, motivated by the perceived need to rationally reconcile our understanding of ourselves with the findings of science. It is not surprising that no consensus emerged from this massive intellectual effort, for the aim was to reconcile what now appears to be valid intuition about ourselves with a profoundly false understanding of the dynamics of the physical world.

The conflict of the idea that our thoughts can influence our actions with the principles of classical physics arises from the fact that according to these principles every feature or property of a physical system is determined

by giving the *locations and velocities* of all of the tiny component parts of these systems. These properties determine all sorts of functional and behavioral properties of conglomerations of these elements. But these features that completely specify the classical-physics conception of physical reality do not rationally entail the existence of the defining characteristic of an experientially reality, namely the way it feels. Thus there is no rational need within classical physics for any experience, say a “pain,” to exist at all. Because there is no necessity within the logical framework of classical physics for experiential realities ever to exist, there is no way to account within that framework for the power of our thoughts to influence anything that the theory by itself does determine.

In quantum theory, on the other hand, the dynamical laws involve conscious thoughts already from the outset. Hence we are not faced with the problem of injecting experiential realities into a conceptual structure that has no rational place for them. The participatory quantum view of the conscious agent opens up possibilities wholly unlike the classical image of the human being as a conglomeration of atoms being mindlessly buffeted about by the chance collisions of atoms.

Although the focus of the above discussion has been on *human* agents, von Neumann’s Process I would function just as well in systems existing long before Homo sapiens roamed the planet earth, and could be utilized by simple and complex systems alike to enhance their chances of survival. This will be discussed.

What impact, if any, can this altered idea of what you are have upon your life? Does not a completely rational approach still lead you to value only your own well being? Perhaps so! But this leads to the further question: What is the self whose well being one values?

Values arise from self-image. Generally one is led by training, teaching, propaganda, or other forms of

indoctrination, to expand one's conception of the self: one is encouraged to perceive oneself as an integral part of some social unit such as family, ethnic or religious group, or nation, and to enlarge one's self-interest to include the interests of this unit. If this training is successful your enlarged conception of yourself as good parent, or good son or daughter, or good Christian, Muslim, or Jew, causes you to give weight to the welfare of the unit as you would yourself. In fact, if well conditioned you may give more weight to the interests of the group than to the well-being of your bodily self.

In the present context it is not relevant whether this human tendency to enlarge one's self image is a consequence of natural malleability, instinctual tendency, spiritual insight, or something else. What is important is that we human beings do in fact have the capacity to expand our image of "self", and that this enlarged concept can become the basis of a drive so powerful that it becomes the dominant determinant of human conduct, overwhelming every other factor, including even the instinct for bodily survival.

But where reason is honored, belief must be reconciled with empirical evidence. If you seek evidence for your beliefs about what you are, and how you fit into nature, then science claims jurisdiction, or at least relevance. Physics presents itself as the basic science, and it is to physics that you are told to turn. Thus a radical shift in the physics-based conception of man from that of an isolated mechanical automaton to that of an integral participant in a nonlocal holistic process that gives form to the evolving universe is a seismic event of potentially momentous proportions.

The quantum concept of man, being based on objective science equally available to all, rather than arising from special personal circumstances, has the potential of providing a universal system of values suitable to all people, without regard to the accidents of their origins. With the diffusion of this Quantum Conception of Human

Beings, science may fulfill itself by adding to the material benefits it has already provided a philosophical insight of perhaps even greater ultimate value.

This issue of the connection of science to values can be put into perspective by seeing it in the context of a thumb-nail sketch of history that stresses the role of science. For this purpose let human intellectual history be divided into five periods: traditional, modern, transitional, post modern, and contemporary.

During the “traditional” era our understanding of ourselves and our relationship to nature was based on “ancient traditions” handed down from generation to generation: “Traditions” were the chief source of wisdom about our connection to nature. The “modern” era began in the seventeenth century with the rise of what is still called “modern science”. That approach was based on the ideas of Bacon, Descartes, Galileo and Newton, and it provided a new source of knowledge that came to be regarded by many thinkers as more reliable than tradition.

The basic idea of modern science was “materialism”: the idea that the physical world is composed basically of tiny bits of matter whose contact interactions with adjacent bits completely control everything that is now happening, and that ever will happen. According to these laws, as they existed in the early twentieth century, a person’s conscious thoughts and efforts can make no difference at all to what his body/brain does: whatever you do was deemed to be completely fixed by local interactions between tiny mechanical elements, with your thoughts, ideas, feelings, and efforts, to the extent that they entered at all, being simply locally determined high-level consequences of the low-level mechanical process, and hence basically just elements of a reorganized way of describing the effects of the microscopic causes.

This materialist conception of reality began to crumble at the beginning of the twentieth century with Max

Planck's discovery of the quantum of action. Planck announced to his son that he had, on that day, made a discovery as important as Newton's.

That assessment was certainly correct: the ramifications of Planck's discovery were eventually to cause Newton's materialist conception of physical reality to come crashing down. Planck's discovery marks the beginning of the "transitional" period.

A second important transitional development soon followed:

In 1905 Einstein announced his Special Theory of Relativity. It denied the validity of our intuitive idea of the instant of time "now", and promulgated the thesis that even the most basic quantities of physics, such as the length of a steel rod, and the temporal order of two events, had no objective "true values", but were well defined only "relative" to some observer's point of view.

Planck's discovery led by the mid twenties to a complete breakdown, at the fundamental level, of the material conception of nature. A new basic physical theory was developed, principally by Werner Heisenberg, Niels Bohr, Wolfgang Pauli, and Max Born, and it brought "the observer" explicitly into physics. The earlier idea that the physical world is composed in part of tiny particles was abandoned in favor of a theory of natural phenomena in which the consciousness of the human observer is ascribed an essential role. This successor to classical physical theory is called "Copenhagen quantum theory".

This turning away by science itself from the tenets of the objective materialist philosophy lent support to Post-Modernism. That view, which emerged during the second half of the twentieth century, promulgated, in essence, the idea that all "truths" were relative to one's point of view, and were mere artifacts of some particular social group's struggle for power over competing groups. Thus each social movement was entitled to its own "truth", which was viewed simply as a socially created pawn in the power game.

The connection of Post-Modern thought to science is that both Copenhagen Quantum Theory and Relativity Theory had retreated from the idea of observer-independent objective truth: science in the first quarter of the twentieth century had not only eliminated materialism as a possible foundation for objective truth, but had discredited the very idea of objective truth in science. Yet if the community of scientists have renounced the idea of objective truth in favor of the pragmatic idea that “what is true for us is what works for us,” then every group becomes licensed to do the same, and the hope evaporates that science might provide objective criteria for resolving contentious social issues.

This philosophical shift has had profound social ramifications. But the physicists who initiated this mischief were generally too interested in practical developments in their own field to get involved in these philosophical issues. Thus they failed to broadcast an important fact: already by mid-century, a development in physics had occurred that provides an effective antidote to both the ‘materialism’ of the modern era, and the ‘relativism’ and ‘social constructionism’ of the post-modern period. In particular, John von Neumann developed, during the early thirties, a form of quantum theory that brought the physical and mental aspects of nature together as two aspects of a rationally coherent whole. This theory was elevated, during the forties---by the work of Tomonaga and Schwinger---to a form compatible with the physical requirements of the Theory of Relativity.

Von Neumann’s theory, unlike the transitional ones, succeeded in integrating into one coherent idea of reality the empirical data residing in subjective experience with the basic mathematical structure of theoretical physics. Von Neumann’s formulation of quantum theory is the starting point of all efforts by physicists to go beyond the pragmatically magnificent but ontologically incomplete Copenhagen form of quantum theory.

Von Neumann capitalized upon the key Copenhagen move of bringing human knowings into the theory of physical reality. But, whereas the Copenhagen approach excluded the bodies and brains of the human observers from the physical world that they sought to describe, and renounced the aim of describing reality itself, von Neumann demanded logical cohesion and mathematical precision, and was willing to follow where this rational approach led. Being a mathematician, fortified by the rigor and precision of his thought, he seemed less intimidated than his physicist brethren by the sharp contrast between the nature of the world called for by the new mathematics and nature of the world that the genius of Isaac Newton had concocted.

The common core feature of Copenhagen and von Neumann quantum theory is the incorporation of human knowings and actions into the structure of basic physical theory. How this is done, and what the consequences are, is the subject of this book. The first step is to leave no doubt about the primary fact that orthodox quantum theory does in fact bring the knowledge of human beings into the essential core of the physical theory.

## 2. REALITY AS KNOWLEDGE.

What are you made of? What is reality made of? What does intuition say about this? What does science say?

The deliverance of intuition on these matters is not unambiguous. Western science and philosophy begins with Thales of Miletus, who proclaimed "All is Water!". Other Greeks believed the primordial stuff to be "Air", or "Earth", or "Fire", and Empedocles settled on all four. On the other hand, Leucippus and Democritus thought everything was composed of tiny invisible, immutable atoms. Two millennia later, it looked like the two atomists had gotten it right: Isaac Newton built his seventeenth-century theory of the universe on the idea of enduring miniscule particles, and John Dalton's atomic hypothesis explained many facts of chemistry.

This notion that everything is composed of small bits of matter encountered, however, a serious difficulty. The earlier idea that "air" was a primary ingredient allowed soul or spirit to be construed as constructed out of one of the primitive substances. But it was hard to see how such a thing as a sensation of the color "red" or "green", or a feeling of "pain" or "joy" could be fully described in terms of a collection of tiny immutable bits of matter careening through space. Given even supreme knowledge and comprehension, how could the motions of billions of particles in a person's brain/body be understood to be the very same thing as a conscious sensation, or the *feeling* associated with the grasping of an idea? One can understand all manner of motions of objects, and of their changing shapes, in terms of the motions of their constituent parts, but there is a rationally unbridgeable gap between the purely geometrical concepts of motions of particles in space and the psychological realities of conscious sensations, feelings, and ideas.

Isaac Newton built his theory upon the ideas of the French philosopher Rene Descartes, who resolved this dilemma concerning the psychological realities by conceiving nature to be built out of two sorts of substances: "matter", which was located in and occupied space, and the "mental stuff" that our thoughts, sensations, and feelings are made of.

This sundering of nature worked well in science for more than two hundred years, but was abandoned by physicists during the twentieth century. The old idea that the material part of nature is made out of tiny bits of reality whose changes are completely fixed by the prior state of the nearby physical stuff---independently of mind---was replaced by a very different picture. Once it became clear that the old notions could not account for the growing mountain of data concerning the properties of the atoms the focus shifted to what the experiments were actually telling us. This opened the door to a new approach that dealt directly with *what we could find out* about the systems being examined, rather than with the system itself. An incredibly beautiful and rationally coherent new kind of mathematical structure eventually revealed itself, but this new mathematics was understood to describe not a self-sufficient physical reality that can exist independently of all minds, but rather our human knowledge of a reality in which our mental activities reside, and which our conscious actions influence.

This original way of conceiving and applying the quantum mathematics was created by a group of physicists working closely with the Danish physicist Niels Bohr, and is called the "Copenhagen interpretation". This approach was closely tied to actual experimental procedures, which involve in the end the human experimenters who design the experiments with some purpose in mind, and later record and interpret the results of their investigations. This practical formulation of the theory defines the way the mathematical structure

is used operationally, and is the touchstone of all later efforts to retain the original predictive power of the quantum rules, while expanding their scope into the domains of cosmology and neuro-dynamics.

The foundation of all attempts to increase the scope of the theory is the work of the great Hungarian mathematician and logician John von Neumann. But before going on to describe von Neumann's contribution it will be helpful, and also fascinating, to appreciate the tremendous change in outlook instituted already by Werner Heisenberg, Niels Bohr, Wolfgang Pauli, and the other founders. For their insights are preserved and expanded in the work of von Neumann.

In the introduction to his book "Quantum theory and reality" the philosopher of science Mario Bunge (1967) said:

"The physicist of the latest generation is operationalist all right, but usually he does not know, and refuses to believe, that the original Copenhagen interpretation---which he thinks he supports---was squarely subjectivist, i.e., nonphysical."

Let there be no doubt about this point. The original form of quantum theory, which is still alive today, is subjective, in the sense that it is forthrightly about relationships among conscious human experiences, and it expressly recommends to scientists that they resist the temptation to try to understand the underlying processes of nature that are responsible for the connections between our experiences that the theory correctly describes. The following brief collection of quotations by the founders gives a conspectus of the Copenhagen philosophy:

Heisenberg (1958a): "The conception of objective reality of the elementary particles has thus evaporated not into the cloud of some obscure new reality concept but into the transparent clarity of a mathematics that represents

no longer the behavior of particles but rather our knowledge of this behavior."

Heisenberg (1958b): "...the act of registration of the result in the mind of the observer. The discontinuous change in the probability function...takes place with the act of registration, because it is the discontinuous change in our knowledge in the instant of registration that has its image in the discontinuous change of the probability function."

Heisenberg (1958b :) "When the old adage 'Natura non facit saltus' (Nature makes no jumps) is used as a basis of a criticism of quantum theory, we can reply that certainly our knowledge can change suddenly, and that this fact justifies the use of the term 'quantum jump'. "[Note: The interventions of Process I are expressed as abrupt changes in *the physical world*, which is construed to be a representation of 'our knowledge.']

Wigner (1961): "the laws of quantum mechanics cannot be formulated...without recourse to the concept of consciousness."

Bohr (1934): "In our description of nature the purpose is not to disclose the real essence of phenomena but only to track down as far as possible relations between the multifold aspects of our experience."

Bohr (1963): "Strictly speaking, the mathematical formalism of quantum mechanics merely offers rules of calculation for the deduction of expectations about observations obtained under well-defined classical concepts."

Bohr (1958): "...the appropriate physical interpretation of the symbolic quantum mechanical formalism amounts only to prediction of determinate or statistical character, pertaining to individual phenomena appearing under conditions defined by classical physics concepts."

The references to "classical physics concepts" is explained in Bohr (1958): "...it is imperative to realize that in every account of physical experience one must describe both experimental conditions and observations by the same means of communication as the one used in classical physics."

Bohr (1958) "...we must recognize above all that, even when phenomena transcend the scope of classical physical theories, the account of the experimental arrangement and the recording of observations must be given in plain language supplemented by technical physical terminology."

Bohr is saying that scientists do in fact use, and must use, the concepts of classical physics in communicating to colleagues the specifications on how the experiment is to be set up, and what will constitute a certain type of outcome. He in no way claims or admits that there is an actual reality out there that conforms to the precepts of classical physics.

In his book "The creation of quantum mechanics and the Bohr-Pauli dialogue" (Hendry, 1984) the historian John Hendry gives a detailed account of the fierce struggles by such eminent thinkers as Hilbert, Jordan, Weyl, von Neumann, Born, Einstein, Sommerfeld, Pauli, Heisenberg, Schroedinger, Dirac, Bohr and others, to come up with a rational way of comprehending the data from atomic experiments. Each man had his own bias and intuitions, but in spite of intense effort no rational comprehension was forthcoming. Finally, at the 1927 Solvay conference a group including Bohr, Heisenberg, Pauli, Dirac, and Born come into concordance on a solution that came to be called "The Copenhagen Interpretation", due to the central role of Bohr and those working with him at his institute in Denmark.

Hendry says: "Dirac, in discussion, insisted on the restriction of the theory's application to our knowledge of a system, and on its lack of ontological content." Hendry summarized the concordance by saying: "On this interpretation it was agreed that, as Dirac explained, the wave function represented our knowledge of the system, and the reduced wave packets our more precise knowledge after measurement."

These quotes make it clear that, in direct contrast to the ideas of classical physical theory, quantum theory is about "our knowledge." We, and in particular our mental lives, have entered into the structure of basic physical theory.

Certainly this profound shift in physicists' conception of the basic nature of their endeavor, and the meanings of their formulas, was not a frivolous move: it was a last resort. The very idea that in order to comprehend atomic phenomena one must abandon physical ontology, and construe the mathematical formulas to be directly about the knowledge of human observers, rather than about the external real events themselves, is so seemingly preposterous that no group of eminent and renowned scientists would ever embrace it except as an extreme last measure. Consequently, it would be frivolous of us simply to ignore a conclusion so hard won and profound, and of such apparent direct bearing on our effort to understand the connection of our knowings to our bodies.

[Von Neumann subsequently rescued physical ontology, and integrated into it the knowledge aspect stressed by the founders: he created a form of quantum theory that incorporates the mental without abandoning the physical.]

Einstein never accepted the Copenhagen interpretation. He said: "What does not satisfy me, from the standpoint of principle, is its attitude toward what seems to me to

be the programmatic aim of all physics: the complete description of any (individual) real situation (as it supposedly exists irrespective of any act of observation or substantiation)." (Einstein, 1951, p.667: the parenthetical word and phrase are part of Einstein's statement.);

and "What I dislike in this kind of argumentation is the basic positivistic attitude, which from my view is untenable, and which seems to me to come to the same thing as Berkeley's principle, {\it it esse est percipi}. (Einstein, 1951, p. 669). [Transl: To be is to be perceived]

Einstein struggled until the end of his life to get the observer's knowledge back out of physics. But he did not succeed! Rather he admitted that: "It is my opinion that the contemporary quantum theory constitutes an optimum formulation of the [statistical] connections." (ibid. p. 87).

He also referred to: "the most successful physical theory of our period, viz., the statistical quantum theory which, about twenty-five years ago took on a logically consistent form. This is the only theory at present which permits a unitary grasp of experiences concerning the quantum character of micro-mechanical events." (ibid p. 81).

One can adopt the cavalier attitude that these profound difficulties with the classical conception of nature are just some temporary retrograde aberration in the forward march of science: one may imagine, as some do, that a strange confusion has confounded our best minds for seven decades, and that the weird conclusions of physicists can be ignored because they do not fit our classical-physics-based intuitions. Or one can try to claim that these problems concern only atoms and molecules, but not the big things built out of them. In this connection Einstein said: "But the `macroscopic'

and 'microscopic' are so inter-related that it appears impracticable to give up this program [of basing physics on the 'real'] in the 'microscopic' domain alone." (ibid, p.674).

The foregoing quotations document the assertion that the original Copenhagen formulation of quantum theory brought the consciousness of the human observer into physical theory in an essential way. The question before us is this: How does this radical change in basic physics affect science's conception of the human person?

### 3. HOW YOUR FREE CHOICES INFLUENCE YOUR BRAIN.

#### The Anti-Newtonian Revolution

From the time of Isaac Newton to the beginning of the twentieth century science relegated consciousness to the role of passive viewer: our thoughts, ideas, and feelings were treated as impotent bystanders to a march of events controlled wholly by contact interactions between tiny mechanical elements. Conscious experiences, insofar as they had any influences at all on what happens in the world, were believed to be completely determined by the motions of miniscule entities, and the behaviors of these minute parts were assumed to be fixed by laws that acted exclusively at the microscopic level. Hence the experiential *felt realities* that make up our streams of consciousness were regarded as either irrelevant to physics or redundant, and were denied fundamental status in basic physical theory.

The founders of quantum mechanics made the revolutionary move of bringing conscious human experiences into the basic theory of physics in a fundamental way. In the words of Niels Bohr the key innovation was to recognize that "in the drama of existence we ourselves are both actors and spectators." [Bohr, Essays 1958/1962 on Atomic Physics and Human Knowledge]. After two hundred years of neglect, our thoughts were suddenly thrust into the limelight. This was an astonishing reversal of precedent because the enormous successes of the prior physics were due in large measure to the policy of excluding all mention of idea-like qualities in the formulation of the laws of nature.

What sort of crisis could have forced the creators of quantum theory to make this radical change of injecting mind into the scientific description of Nature? The answer to this question begins with a discovery that occurred at the beginning of the twentieth century. In the year 1900 Max Planck discovered and measured the "quantum of action." Its measured value is called "Planck's Constant." This constant specifies one of three basic quantities that are built into the fundamental fabric of the physical universe. The other two are the gravitational constant, which fixes the strength of the force that pulls every bit of matter in the universe toward every other bit, and the

speed of light, which controls the response of every particle to this force, and to every other force. The integration into physics of each of these three basic quantities generated a monumental shift in our conception of nature.

Isaac Newton discovered the gravitational constant, which linked our understanding of celestial and terrestrial dynamics. It connected the motions of the planets and their moons to the trajectories of cannon balls here on earth, and to the rising and falling of the tides. Insofar as his laws are complete the *entire physical universe* is governed by mathematical equations that link every bit of matter to every other bit, and that moreover fix the complete course of history for all times from conditions prevailing in the primordial past.

Einstein recognized that the "speed of light" is not just the rate of propagation of some special kind of wave-like disturbance, namely "light". It is rather a fundamental number that enters into the equations of motion of every kind of material substance, and that, among other things, prevents any piece of matter from traveling faster than this universal limiting value. Like Newton's gravitational constant it is a number that enters ubiquitously into the basic structure of Nature. But important as the effects of these two quantities are, they are, in terms of profundity, like child's play compared to the consequences of Planck's discovery.

Planck's "quantum of action" revealed itself first in the study of light, or, more generally, of electromagnetic radiation. The radiant energy emerging from a tiny hole in a heated hollow container can be decomposed into its various frequency components. Classical nineteenth century physics gave a clean prediction about how that energy should be distributed among the frequencies, but the empirical facts did not fit that theory. Eventually, Planck discovered that the correct formula could be obtained by assuming that the energy was concentrated in finite packets, with the amount of energy in each such unit being directly proportional to the frequency of the radiation that was carrying it. The ratio of energy to frequency is called "Planck's constant". Its value is extremely small on the scale of normal human activity, but becomes significant when we come to the behavior of the atomic particles and fields out of which our bodies, brains, and all large physical objects are made.

Planck's discovery shattered the classical laws that had been the foundation of the scientific world view. During the years that followed many experiments were performed on atomic particles and it was repeatedly found that the classical laws did not work: they gave well defined predictions that turned out to be flat out wrong when confronted by the experimental evidence. The fundamental laws of physics that every physics student had been taught, and upon which much of the industrial and technological world was based, were not correct. But more importantly and surprisingly, they were failing in such a way that no mere tinkering could ever fix. There was something fundamentally amiss. No one could say how these laws, which were so important, and had seemed so perfect, could be fixed. No one could foresee whether a new theory could be constructed that would explain these strange and unexpected results, and restore rational order to the cosmos. But one thing was clear to those working feverishly on the problem: Planck's constant was somehow at the center of it all.

### Quantum Theory

Werner Heisenberg was one of a band of young physicists assembled by Niels Bohr at his institute in Copenhagen for the purpose of solving this riddle of the breakdown of the principles underlying classical physics. In 1925 he discovered the completely amazing and wholly unprecedented solution to the puzzle: the quantities that classical physical theory was based upon, and which were thought to be numbers, *are not numbers at all* ! Ordinary numbers, such as 2 and 3, have the property that the product of any two of them does not depend on the order of the factors: 2 times 3 is the same as 3 times 2. But Heisenberg discovered that one could get the correct answers out of the old classical laws if one decreed that the *order in which one multiplies* certain quantities matters!

This "solution" may sound absurd or insane. But mathematicians had already discovered that many completely coherent and logically consistent generalizations of ordinary mathematics exist in which the order in which one multiplies quantities matters. Ordinary numbers that we use for everyday things like buying a loaf of bread or paying

taxes are just a very special case from among all of the allowed mathematical possibilities. In this simplest case, A times B happens to be the same as B times A. But here is no logical reason why Nature should not exploit one of the more general cases, and there is no compelling reason why our physical theories must be based exclusively on ordinary numbers. Heisenberg's theory, which became Quantum Theory, exploits the more general logical possibility.

Now all this may sound like a lot of mathematical tomfoolery, but the key point is that it led to a revision of the scientific conception of nature of reality that is so profound that impacts upon the lives of ordinary people.

An example of the change introduced by Heisenberg may be helpful.

In classical physics the center-point of each object has, at each instant, a well defined location, which can be specified by giving its three coordinates ( $x$ ,  $y$ ,  $z$ ) relative to some coordinate system. For example, the location of a spider dangling in a room can be specified by letting  $z$  be its distance from the floor, and letting  $x$  and  $y$  be its distances from two intersecting walls. Similarly, the *velocity* of that dangling spider, as she drops to the floor, blown by a gust of wind, can be specified by giving *the rate of change* of these three coordinates ( $x$ ,  $y$ ,  $z$ ). If each of these three rates of change, which together specify the velocity, are multiplied by the weight (=mass) of the spider, then one gets three numbers, say ( $p$ ,  $q$ ,  $r$ ), that define the "momentum" of the spider. So in classical physics you might use the set of three numbers called ( $x,y,z$ ) to represent the position of the center point of an object, and the set of three numbers called ( $p,q,r$ ) to represent the momentum of that object. These are just ordinary numbers that obey the commutative property of multiplication that we all, hopefully, learned in 3<sup>rd</sup> or 4<sup>th</sup> grade:  $x*p$  equals  $p*x$ , where  $*$  means multiply.

Heisenberg's analysis showed that in order to make the formulas of classical physics describe quantum phenomena,  $x*p$  must be different from  $p*x$ . Moreover, he found that the difference between these two products must be Planck's constant. [Actually, the difference is Planck's constant multiplied by the imaginary unit  $i$ ,

which is a number such that  $i$  times  $i$  is minus one. Hey, no one said quantum mechanics was going to be easy.] Thus quantum theory was born by recognizing, or declaring, that the symbols used in classical physical theory to represent ordinary numbers actually represented mathematical objects such that their ordering in a product is important. The procedure of creating the mathematical structure of quantum mechanics from classical physics by replacing ordinary numbers by these more complex objects is called "quantization."

This idea of replacing the numbers that specify where a particle is, and how fast it is moving, by mathematical quantities that violate the simple laws of arithmetic may strike you---if this is the first you've heard about it---as a giant step in the wrong direction. You might mutter that scientists should try to make things simpler, rather than abandoning one of the things we really know for sure, namely that the order in which one multiplies factors does not matter. But against that intuition you should bear in mind that this change works beautifully in practice: all of the tested predictions of Quantum Theory are borne out, and these include predictions that are correct to the incredible accuracy of one part in a hundred million. There is something very very right about quantum theory. But what is important in the larger context of human life is that, as we shall discuss later, it disrupts old laws of physics in just such a way as to bring your conscious thoughts into physics as causal agents with "free choices": choices that can influence your behavior but are controlled neither by the deterministic laws that fix the motions of the elementary particles, nor by any other known law. This revision of the physics severs in one stroke the logical chain that had perplexed and hobbled philosophy for two and a half centuries. It converts the physical world from a collection of tiny material particles and local fields to a mathematical structure that represents *knowledge or information*, and also *tendencies for future knowings to occur*. Classical-type matter does not exist: it has been replaced by idea-like realities, which, however, have enough matter-like properties to ensure all of the empirically validated consequences of classical physics.

## Matrix Mechanics

The idea that the product  $AB$  of two quantities,  $A$  and  $B$ , is different from  $BA$  may seem weird, or impossible. But this property is completely understandable if  $A$  and  $B$  are “matrices.” Quantum mechanics is sometimes called “matrix mechanics” because it can be understood as a consequence of replacing ordinary numbers by matrices. But what are “matrices?”

An  $N$ -by- $N$  matrix is a square array of numbers arranged in  $N$  rows each having  $N$  numbers. Or one can think of it as consisting of  $N$  columns each having  $N$  numbers. So it is a square array of numbers with  $N$  rows and  $N$  columns. If  $M$  is a matrix then mathematicians label the individual number that lies in row number  $i$  and column number  $j$  by  $M(i,j)$ . Thus  $M(2,3)$  is the number that lies in the second row and the third column of the matrix  $M$ . If you abhor math you can ignore these details, but you do need to know that matrices are well defined mathematical objects: there is no vagueness about them. Moreover, the product  $C=AB$  is well defined. The rule is  $C(i,j)=A(i,k)B(k,j)$  summed over all  $N$  values of  $k$ . By using this rule one can easily verify, already for  $N=2$ , that  $AB$  is usually different from  $BA$ .

I shall not use these formulas in any explicit way. But it is important to recognize that  $AB$  and  $BA$  are both well defined, and are generally different.

In quantum theory each physical system, from an individual electron, to a small device, to a human brain, and to still larger systems, is represented by an  $N$ -by- $N$  square matrix  $S$  called a density matrix.

One technical problem is the fact that the number  $N$  is generally infinite. Much of von Neumann’s mathematical work in quantum theory was devoted to the resolution of possible ambiguities arising from this fact. Thanks to von Neumann’s work we can, for our purposes, gloss over the mathematical subtleties and simply imagine matrices whose rows and columns are both labeled by a set  $I$  of continuous variables, such as the set of variables  $(x,y,z)$  that label the location of the center point of a classically conceived particle or

object. This means that each possible location  $I$  of the center point of a classically conceived particle or object occurs twice in the quantum description of the state  $S$  of that system, once as a label on the *rows* of the matrix  $S$  that specifies the state of the object and once as the label on the *columns* of  $S$ . The so-called “diagonal” elements  $S(I,I)$  in which the row and column both correspond to the *same* location  $I$  of the classically conceived particle or object are the elements of  $S$  most closely connected to classical physics. However, the “off-diagonal” elements, which would correspond to the center of the classically conceived object’s being in two different locations at the same time, also contribute to the quantum dynamics.

### The Cloud-Like Forms

A crucial feature of matrix mechanics is that, even if we consider only the diagonal elements  $S(I,I)$  of  $S$ , which are the elements most closely connected to classical ideas, no object, large or small, has a well defined location: every object, and combination of objects, is represented by a density matrix  $S$  that has “large” values on a set of diagonal elements  $S(I,I)$  such that  $I$  covers some finite region: the *center* of the physical system, as represented by the corresponding matrix  $S$ , is not confined to a point, but is a smeared out cloud-like structure that extends over some finite region. Moreover, this cloud tends to expand with the passage of time under the action of the equations of motion that are generated by the “quantization” procedure. This conversion of the location of the center point of an object from a moving point into an expanding cloud is a key feature of quantum theory.

### The Problem With Experience

This expanding cloudlike character of physical systems produces a very serious problem when it comes to relating the mathematical description given by quantum theory to human experience. Each of us experiences any visible physical object as having a fairly well defined location: its center is not experienced as being ambiguously smeared out over several centimeters, or perhaps even meters or kilometers. In classical physics this experiencing of definite locations is easy to understand. Each small object has a well defined position at each moment, and one can imagine bouncing light off the object,

then following the reflected light from the object to some particular small region of the retina. The excitation of the nerves in this portion of the retina could cause the brain to evolve into a state that would depend upon where the light hit the retina. That location on the retina would depend upon where the object was located. Hence the ensuing visual experience could easily depend upon where the object was located: the person could “see where the object is situated” because the state of his brain would depend upon where the object was located.

But if one tries to follow the same reasoning in quantum theory then the cloudlike character of an object causes a problem: it would lead to a corresponding cloudlike state of the brain. The brain would evolve into a smeared-out structure in which *all* of the possible locations of the object are represented: no single location of the object would be singled out and distinguished from many neighboring locations. Thus the experience of the observer would, it would seem, contain components corresponding to a whole set of different locations of the object. But only one of these possibilities is experienced by us. The problem then is: How does one particular experienced location of the (center-point of the) observed object get singled out from all the others that occur, undifferentiated, in the cloudlike structure that represents, in the theory, *the center point* of the observed object. Because there is nothing in the physical state *S* of the object itself that singles out one location in the cloud from all the others the founders of quantum theory turned to the other part of nature that is involved in the experiencing of a definite location, namely the experiencing agent.

The basic problem, therefore, is that the replacement of simple numbers by matrices---i.e., by huge arrays of numbers---tends to smear everything out, including the states of the brains of the observers. Consequentially, it would seem that, according to the theory, each physical object should appear to be everywhere, rather than somewhere. This disparity between the raw theory and ordinary experience is the fundamental problem that was resolved by the founders of quantum theory by bringing the actions of human experimenters into the dynamics in an essential way.

## The Copenhagen Solution: Bring In "The Observer"

In both the original Copenhagen quantum theory and von Neumann's reformulation of it the dynamical rules involve an effect of an action by a human agent upon the state of an observed physical system. But this agent is treated differently in these two versions. In particular, "The Observer" in the Copenhagen version differs greatly from what is normally meant by this term: it involves an extension of the human observer outside his physical body.

Bohr mentioned several times the example of a man with a cane: if he holds the cane loosely he feels himself to extend only to his hand. But if he grips the cane firmly then the outer world seems to begin at the tip of his probing cane. Correspondingly, "The Observer" in Copenhagen quantum theory includes not only the body and mind of the experimenter himself, but also the measuring devices that he uses to probe some "observed system" that lies outside of his extended "self". Thus nature is imagined to be cleaved into two parts, which are described in different ways. The outer "observed system" is described in terms of quantum mathematics, whereas the inner "observing system" is described in terms of experiential facts.

Because Copenhagen quantum theory treats the measuring instruments as part of the observer these devices are described in terms of our experiences of them, not in terms of their atomic constituents. Thus the dynamics becomes an interaction between this extended observer, which is described in experiential terms, and the reality that he is probing, which is described by an evolving matrix. The laws of physics must therefore be expanded from laws that govern simply the physical world alone to laws governing the dynamical interplay between an experiencing agent and an external-to-himself system that he is probing.

But how does one enlarge physical theory to encompass a dynamical interplay between an experientially/psychologically described agent and the physically/geometrically described object he is studying?

The Copenhagen solution exploits the apparently innocent fact that in order to extract precise information from nature the experimenter has to put in place an appropriate measuring device. Thus his action

results in the coming into being of some particular experimental set-up that probes nature in some particular way. The essential feature of these devices is that they never give answers to questions of the form “What is the value of  $X$ ?” where  $X$  ranges over a continuous set of values. Rather they answer questions with a discrete set of possible answers: Does the set-in-place Geiger counter give an audible click or not?

What actually happens in the scientific experiment is that the experimenter performs the intentional act of structuring the world (i.e., setting up the experimental arrangement) in such a way as to cause the world either to return a certain recognizable response, or fail to return that response. Thus the experimenter, by his intentional act, structures the part of nature under his control in a way that poses, or puts to nature, a question that has a discrete answer, ‘Yes’ or ‘No’. In other words, the agent acts in such a way that the devices that are considered to be extensions of his own body are positioned in such a way that if he experiences a response---hears the Geiger counter click--- then he will know something about the external system that he is studying: he will have acquired one bit of information.

But this essentially psychological process, which is based on the agent’s particular intentions and actions, is not described by the quantum generalization of the classical laws of motion. Indeed, if the only process in Nature were that latter process, which would then govern also the experimenter himself, then the experimenter and his devices would be smeared out clouds generated by the evolution of the universe since the big bang. There would be no particular locations of devices singled out from a continuous background of possibilities. This is because that dynamical process is essentially continuous in both time and space, and generates only smeared out locations that generally expand with time. The founders of quantum theory thus introduced the actions of the agents into the theory in order to extract an element of definiteness or discreteness from an otherwise completely amorphous structure.

Copenhagen quantum theory is thus formulated in a realistic and practical way. It is structured around the activities of human agents, who can freely elect to probe nature in any one of many possible

definite ways. Bohr emphasized the freedom of the experimenters in passages such as:

"The freedom of experimentation, presupposed in classical physics, is of course retained and corresponds to the free choice of experimental arrangement for which the mathematical structure of the quantum mechanical formalism offers the appropriate latitude."

This freedom of the agent stems from the fact that in Copenhagen quantum theory the human experimenter stands outside the system to which the quantum laws are applied. Those quantum laws are the only precise laws of nature recognized by that theory. Thus, according to the Copenhagen philosophy, there are no presently known laws that govern the choices made by the agent/experimenter/observer about how the observed system is to be probed. This choice is, in this very specific sense, a "free choice."

#### The Von Neumann Solution: Bring in The Brains

This Copenhagen solution involves separating the dynamically unified physical world into two parts, the observing system and the observed system, that are described in very different ways. The agent's intentional act of performing a measurement causes a sudden discrete change in the state of the observed system. This formulation works beautifully in practice, but the severing of the unified physical world into two parts that are described in different ways, and the unexplained disruption of the normal physical laws produced by the proximity of the measuring device to the observed system, is a source of great dissatisfaction among those who seek a rationally and dynamically coherent understanding of what is actually going on.

Von Neumann circumvented this unnatural bifurcation of the physical world by devising a rigorous formulation of quantum theory that treats the entire physical world, including the bodies and brain of the human agents, as belonging to the physical part of reality that is uniformly described by the quantum mathematics. Then the brain of the agent becomes the observed system, and the intentional act of the agent produces a change in the physical state his brain. However, the intentional act involves the free choice of which particular

measurement act to perform, and this discrete choice must still be made by some process other than the continuous dynamical process that arises from the quantization of the classical laws.

### Process I and Process II

This process of “measurement” is of such essential importance to quantum theory that von Neumann calls it Process I. He calls the quantized version of the classical dynamical process Process II. Thus, according to both the Copenhagen and von Neumann formulations, the quantum dynamics involves *two processes*. One of them is analogous to the local deterministic process of classical physics. This process, Process II, applied to the brain, is a “bottom up” process, in the sense that, like the dynamical process of classical physics, it is expressed in terms of contact interactions between local properties and, like its classical analog, is deterministic. However, the other process, Process I, is “top down.” It is a volitionally controlled action that produces a specific sort of effect on the brain of the agent whose volition is guiding the action.

The relationship between the mind and the brain of the agent is therefore specified in von Neumann quantum theory not by some abstract metaphysical correspondence that is *added onto* the already complete dynamical theory in order to link a dynamically irrelevant mind to the physical universe. Rather, this relationship is a *dynamical* process that is a necessary feature of the physical theory itself. It consists of a causal effect of a conscious intentional action of an agent upon his own brain: an action of mind on brain.

Von Neumann pushed the physical world out to include the brain of the agent, but gave no prescription for specifying how the choice of action associated with Process I is made. Thus at this stage of the developments of physical theory the choice on the part of the agent that specifies which of the possible Process I events actually occurs remains a “free choice,” in the specific sense that it is not fixed either statistically or deterministically by the laws of contemporary physical theory.

The Process-I connection between intentional thoughts and the physical brain is, within the von Neumann ontology, the foundation of

human personhood. Hence I must describe it here in a way that general readers can understand. Physicists have their own relevant jargon for describing Process I, and rather than giving vague restatements I shall, instead, describe the process in the language used by physicists, and explain the meaning of the relevant terms.

### Process I

Quantum theory, as already noted, replaces numbers by matrices. This complexity permits the entry of new conceptions that escape the narrow bounds of what classical physics allows. This shift to matrix mechanics is a wonderful boon to humankind, for it allows us to reconcile our intuitive idea of what we are with the basic laws of science.

The complexity of these huge infinite-dimensional matrices actually engenders a certain conceptual simplicity. The entire brain of the agent is represented by an infinite-dimensional matrix. Hence, conceptually, the same matrix idea applies just as well to a whole brain as to a single coordinate  $x$  of single particle.

Suppose the infinite-dimensional matrix that represents the entire brain of the agent (or perhaps the portion of that brain that is associated with a conscious experience) is called  $S$ . Then the key question is: What happens to  $S$  when a Process I event occurs? This action constitutes the effect of mind on brain.

This action involves “projection operators.” A matrix  $P$  is a projection operator if and only if  $PP = P$ : i.e., if  $P$  times  $P$  is  $P$  itself. There are exactly two ordinary numbers that have this property, zero and one: zero times zero is zero, and one times one is one. No other numbers have this property, But for any number  $N$  greater than 1 here are an infinite number of matrices  $P$  such that  $P$  is an  $N$  dimensional square matrix, and  $P$  times  $P$  is  $P$ .

The von Neumann Process I describes the encoding in the brain of an agent of an intentional act by that agent. This encoding is specified by a projection operator  $P$ , which acts as a whole on the entire state  $S$  of the brain. The action of Process I is this: If the symbol “ $I$ ” stands for the matrix that has one (unity) in every diagonal

location (i.e.,  $I(i,i) = 1$  for every value of  $i$ ) and zero in every other location (i.e.,  $I(i,j) = 0$  for  $i$  different from  $j$ ) then the effect of Process I is to replace  $S$  by  $S' = PSP + (I-P)S(I-P)$ .

The two terms  $PSP$  and  $(I-P)S(I-P)$  are called the “branches” of the new state  $S'$ . The branches  $PSP$  and  $(I-P)S(I-P)$  correspond to the experiential answers ‘Yes’ and ‘No’, respectively, to the probing question. This Process I specifies the mind-brain connection in von Neumann quantum theory.

### The Action of Mind on Brain

To complete the general picture I must explain the connection between the intentional action, considered as a mental act, and the associated projection operator  $P$ , which acts upon the state  $S$  of the brain of the agent.

Quantum theory provides a conceptual framework that, unlike classical physics, brings mental intentional actions into the dynamics in fundamental way. Process I specifies that the intentional mental effort to act in some particular way produces the effect  $S \rightarrow S' = PSP + (I-P)S(I-P)$  on the state  $S$  of (some pertinent aspect of) the brain. The action of the projection operator  $P$  is to select out and actualize, from among all of the possible patterns of brain activity, some particular subset of patterns. If the actualization of this particular pattern is to bring about the intended physical action then the actualization of this brain pattern must, evidently, if sustained, tend to cause the intended action to occur.

Descartes himself allowed mind to act on brain in some such way. It was the philosophers and scientists who followed him who insisted that the geometric conceptualization of the physical world introduced by Descartes, and utilized by Newton, was so complete as leave no room for any causally potent thing other than conglomerations of the micro-elements that classical physics describes. But the loosening of the classical determinism expressed in the cloudlike character of the quantum physical world, coupled with the explicit introduction of agents that are not governed by the known laws, but perform intentional acts represented explicitly by Process I, changes the situation completely.

The fact that the felt effort is linked to just the right sort of effect on the brain, namely the very effect that will tend to cause the intended action to occur, might seem at first mysterious. But it has a naturalistic explanation. We see at work, particularly in the infant, but also throughout life, the trial-and-error process of discovering what kind of experiential effort tends to produce what kind of experiential feedback. So if there exists the general sort of Process I mind-brain connection called for by von Neumann quantum theory then it is no deep mystery that biological organisms should develop in ways that would exploit it, and that human beings should be able to learn by trial and error which sorts of efforts tend to produce which sorts of feedbacks.

I shall elaborate upon the efficacy of this Process I intervention. But the essential point of this book has now been made. According to classical mechanics, everything that happens in the physical world is determined by a single *bottom up* local deterministic physical process, and we ourselves are, consequently, robotic automata. This does not mean that in classical physics high-level processes have no effect on low-level processes. Macroscopic entities such as wheels, pistons, and weather patterns can cause things to happen, and can causally influence the course of low-level events. But those top down classical processes are merely partial and approximate re-expressions of the bottom up micro-process, which is itself dynamically complete. But in quantum theory, in its von Neumann formulation, the human agents are governed by *two* processes. One of them, Process II, is a bottom up local deterministic process that is specified by quantizing the classical law. But this Process II by itself does not yield any explanation of, or predictions concerning, relationships between our human experiences. Another process, Process I, is needed to complete the theory, and it is a genuine top down process in the sense that it expresses causal effects of experientially felt intentions upon the brain/body of the experiencing agent, and it involves choices that are not controlled or determined by any known law or rule of nature.

#### **4. DOUBLE SLITS, NERVE TERMINALS, AND THE NEED TO USE QUANTUM BRAIN DYNAMICS.**

Most neuroscientists and philosophers who ponder the relationship of consciousness to brain process want to believe that classical physics will do. That belief would have been reasonable during the nineteenth century, but now, in the twenty-first, it is rationally untenable. The general dynamical reason why quantum theory must be used when the effects of consciousness are involved was described in the preceding chapters: brains are the arena of where the crucial Process I acts. This process specifies the interaction between a person's stream of consciousness and the activity in his brain, and it drops out when one goes over to the classical approximation. So ignoring quantum effects in the study of the mind-brain connection would, from the perspective of von Neumann quantum theory, be totally unjustified.

But the further question is a quantitative one: How important are the quantum (i.e., cloudlike) properties of, say, ions in brain dynamics? That these properties are very important is made particularly evident by an examination of the dynamics of nerve terminals.

Nerve terminals lie at the junctions between two nerves, and mediate the connection between them. The way they work is this. Each "firing" of a nerve sends an electrical signal along that fiber. When this signal reaches the nerve terminal it opens up tiny holes in the terminal membrane, through which calcium ions flow into the interior of the terminal. Within the terminal are "vesicles", which are small sacks containing chemicals called neurotransmitters. The calcium ions migrate from their entry holes to special sites, where they trigger the release of the contents of a vesicle into a gap between the terminal and a neighboring nerve. The released chemicals influence the tendency of the neighboring nerve to fire. Thus the nerve terminals, as connecting links between nerves, are basic elements in brain dynamics.

The holes through which the calcium ions enter the nerve terminal are called "ion channels." At their narrowest points they are not much larger than the calcium ions themselves. This extreme smallness of the opening in the ion channels has profound quantum mechanical

import. The consequence is essentially the same as the consequence of the narrowness of the slits in the famous double-slit experiments, which prove the wave nature of photons, electrons, and ions.

In all these cases the smallness of the hole or slit restricts the lateral dimension of the beam. Consequently, the lateral velocity is forced by the *quantum uncertainty principle* to become large. This causes the cloud (or wave packet) associated with the particle to balloon out over an increasing area as it moves from the tiny hole or slit to the target where it will be absorbed on some small site.

This spreading of the ion wave packet means that the ion may or may not be absorbed on the triggering site. Accordingly, the vesicle may or may not release its contents. Consequently, the quantum state of the vesicle becomes a quantum superposition consisting of a state where the neurotransmitter is released and a state where the neurotransmitter is not released. This quantum splitting occurs at every one of the trillions of nerve terminals.

What is the effect of this *necessary* incursion of the cloud-like nature of matter into the evolving state of the brain?

A principal function of the brain is to receive clues from the environment, form an appropriate plan of action, and direct the body/brain action specified by the selected plan of action. The exact details of the plan will, for a classical model, obviously depend upon the exact values of many noisy and uncontrolled variables. In cases close to a bifurcation point of the dynamics the effects of noise might even tip the balance between two very different responses to the given clues: e.g., tip the balance between the ‘fight’ or ‘flight’ response to some shadowy form.

The effect of the independent superpositions of the “release” or “don’t release” options at each of the trillions of nerve terminals will be to cause the quantum mechanical state of the brain to become a collection of different states representing different alternative possible plans of action. As long as the brain dynamics is controlled wholly by ProcessII---which is the quantum generalization of the Newtonian laws of motion in classical physics---all of the various alternative possible plans of action exist in parallel, with no one plan of action

singled out as the one that will actually occur. Some other process, beyond the local deterministic Process II, is required to select some particular real course of physical events from the smeared out mass of possibilities generated by all of the alternative possible combinations of vesicle releases at all of the trillions of nerve terminals.

But what is this other process that selects distinct alternatives with well defined probabilities from the amorphous conglomeration of overlapping possibilities. According to both the Copenhagen and von Neumann formulations of quantum theory it is Process I.

Curiously, those physicists who attempt to improve upon these orthodox formulations of quantum theory see the problem with these mainline views as this intrusion of the observer into physics: their aim is to try to rid quantum theory of “the observer”, who by virtue of his subjective nature, must, in their opinion, be excluded from science.. This stance is maintained in direct opposition to what would seem to be the most profound advance in physics in three hundred years, namely the overcoming of the most glaring failure of classical physics, its inability to accommodate us, its creators. The most remarkable and salient feature of quantum theory is that the mathematics has a dynamical gap that, by virtue of its intrinsic form, provides a perfect place for Homo sapiens as we know and experience ourselves. That was the conclusion recognized by the founders of quantum theory already in 1926, and clarified by von Neumann in 1932. In view of the severe philosophical difficulties with the classical mechanical conception of man it is odd that anyone would want to revert to it.

## 5. AGENTS AND EVOLUTION.

Human beings play a singular role in Copenhagen quantum theory: within that scheme science is viewed as a human endeavor, performed by human beings for human beings. Still, most scientists believe that *something* was going on before Homo sapiens arrived on the scene, and many hold that the task of science will not be finished until we have a science-based idea of what that something was, and how our species emerged from it.

My intention here is to find the place of human beings in a broader non-anthropocentric setting, and I believe that this can be done by building upon the foundation laid by the creators of quantum theory, rather than by retreating to a mechanistic conception of man that ignores consciousness, or tries to replace it by something else, such as classically describable brain processes. Indeed, the approach of scientists and philosophers who base their thinking on the classical conceptualization of human brains depends on a promissory note that can never be redeemed.

That promise, or completely unsupported hope, is that *someday* we shall be able to understand how a conscious experience---a feeling or knowing---can either *be*, or *be a necessary consequence of*, a structure built exclusively out of the elements specified by classical mechanics. However, as already noted in Chapter 1, the classical concepts and laws entail all kinds of microscopic and macroscopic geometric, behavioral, and functional properties, but nothing in those concepts and principles can *ensure* or *dictate* that some changing arrangements of numbers assigned to space-time points, which is basically all that classical physics can ever provide, will *necessarily* be accompanied by, say, a “painful feeling”.

Thus feelings can be only gratuitous---not rationally entailed---add-ons to any structure built solely from entities possessing only the properties specified by the classical concepts. Such supernumeraries, being non-entailed either rationally, dynamically, or logically, can be stripped away without effecting the course of physical events prescribed by the theory, and hence are devoid of survival value. Nor can it be argued that feelings *must* emerge from such systems because we ourselves are the living proof. For we

ourselves are certainly not built out of elements that conform to the idealized unphysical concepts that are the basis of classical physics. We, insofar as contemporary science has correctly informed us, are built out a very different kind of stuff that is more like information and tendencies for experiences to occur, than like classical matter.

In short: in order to get something like consciousness out of a theory one must put something like consciousness in. Orthodox quantum theory already requires, in order to yield well defined predictions, the existence of Process I, which by its intrinsic nature is both a dynamically efficacious element of the theory and a link between the experiential and physical aspects of the theory. Thus quantum physics already provides, *as an essential feature of the dynamics*, what was formerly provided by metaphysics, namely a link between the physical attributes of an agent, which are described in geometrical terms, and the experiential aspects that are described in psychological terms?

So far I have restricted myself to the orthodox framework created by the founders of quantum theory, and developed by John von Neumann. The focus of those works was on *human* agents, and on intentional actions that created scientific experiments. I shall apply the same equations and ideas more generally.

So how does the evolutionary scenario work?

According to this theory, the universe initially evolves under the governance of Process II alone. All possibilities are mechanically generated by this evolving cloud-like state. Given the nature of the laws implemented by these laws---which support, among other things, the possibility of the formation of organic molecules---the set of all possibilities will eventually lead to the formation of potential agents, which are simply mechanical subsystems that exist for a time in equilibrium with their environment, as (perhaps rudimentary) stimulus-response (input-output) system. These systems can be roughly conceived of as smeared out cloudlike *collections* of classical states that tend to endure for intervals of time in communication with their environments.

Each of these quasi-stable subsystems has, due to its wave-like (cloudlike) nature a tendency to degenerate into less cohesive states. However, nature has armed all potential agents with a counter-weapon: access to Process I, which is able by means of the Quantum Zeno Effect (to be described presently) to preserve over extended periods, in the face of all sorts of disruptive processes, the physical integrity of the agent.

We have as our building blocks the assumed existence of Processes I and II, and the known existence of feelings. This brings us to the critical questions: (1) What determines when a Process I event occurs? (2) What determines the specific form of that event? And (3) How is that event related to the “feeling” aspect of nature?

Due to the inherently cloud-like quality of physical systems the quantum state of a potential agent will tend to evolve into a collection of states that represent alternative possible courses of action. Within that collection there may be a maximal state of high organization (low entropy) in which various modules---partially autonomous subsystems---within the agent act together in mutual support to form a state of quasi-stable equilibrium. This state will extend over a large region, and hence cannot be grasped or identified as a whole by the dynamically local Process II. But it can be specified by a projection operator  $P$  acting on some slowly changing degrees of freedom of the agent. The feel associated with Process I can be identified as the grasping of this state of non-discordant organization. This enduring state of quasi-stable equilibrium is the state  $PSP$  specified by Process I.

One might object that if the effect of this “feel” is precisely definable in terms of the mathematically defined projection operator  $P$ , then the “feels” could, just as in the classical case, be eliminated from the dynamics, rendering the feels superfluous and without causal efficacy. But the situation in this regard is very different from the classical one. In the classical case an ontology (i.e., reality) is specified that has no hint of the existence of anything like a “feeling.” And there is nothing physical for a feeling to do that is not already done by the classical physical process. But in quantum theory the physically described Process II, does not by itself lead to a well defined predictive theory, or to any understanding of the structure of our human experiences. Thus orthodox quantum theory introduces

Process I not to link consciousness to a theory that is already dynamically complete, but rather to complete the dynamics in a way that will bring the theory into concordance with our conscious experience. This process must involve “feelings,” if, following William James, we recognize all experiential happenings to be feelings of one kind or another.

This grasping event is represented in the mathematics by a von Neumann Process I event. Each such event separates the prior physical reality into two independent branches, ‘Yes’ and ‘No’. The ‘Yes’ branch, PSP, contains the non-discordant state of organization, which persists long enough for its physical traces to be etched into the physical structure of the agent, and for the action that it specifies to be initiated. The left-over ‘No’ branch  $(I-P)S(I-P)$  would not in general be associated with a quasi-stable state of equilibrium, and hence should not be directly connected to a (recollected) experience. However, subsequent Process I events can occur in either one of the two branches, and this would allow experiences to become associated eventually with either branch.

The theory assigns a statistical weight to each branch. The weights associated with the ‘Yes’ and ‘No’ branches are given by the formulas  $\text{Tr PSP} / \text{Tr S}$  and  $\text{Tr } (I-P)S(I-P) / \text{Tr S}$ , respectively, where for any matrix  $M$  the expression  $\text{Tr } M$  represents the sum of all of the ‘diagonal elements’  $M(i,i)$  of  $M$ . (You need not understand these formulas, but should know that such probability formulas exist.)

Subjectively, these statistical weights determine the “probabilities” that the agent will experience the ‘Yes’ feeling or will not experience that feeling. They determine also the probability that another agent who is observing first agent will observe his actions to accord with the state PSP or  $(I-P)S(I-P)$ .

The simplest explanation of these empirical facts is that “Nature chooses” either the state PSP or the state  $(I-P)S(I-P)$  in accordance with a “propensity” or “objective tendency” specified by the above formulas. However, this idea of a real objective eradication of one branch or the other leads to the conclusion that Process I events occurring in distant parts of the universe are linked together by “instantaneous” action-at-a-distance effects.

The argument that establishes the need for faster-than-light influences is too technical to be included in the body of this text. I have put it into an appendix, for those willing to work a bit harder.

Some physicists find faster-than-light action-at-a-distance unacceptable, even though it generates no conflict with experience, and prefer to believe that no real objective choice is made between the two states, but rather that *it only seems like that*. Von Neumann makes no commitment as to whether there is or is not a real objective eradication of branches, and I shall follow his lead of not becoming embroiled here in that controversy. Process I merely separates the state of the brain (and therefore the universe) into two distinct branches for the ongoing physical process: it does not choose between them.

The really important fact is this: If the rapidity of nearly identical Process I events in a chain of 'Yes' choices is sufficiently great then, a straightforward application of the probability formulas given above shows that, the probability associated with this evolving 'Yes' state will not decrease as quickly as it otherwise would. Thus this state of organization can sustain itself by means of this "Quantum Zeno Effect" in the face of mechanical processes that tend to destroy it. This means that agents that have structures that tend to produce suitable sequences of Process I events would enjoy a survival advantage over competitors that lack such structures. Our own large capacity to use Process I would then be an example of the adaptive tendency of living organisms to exploit the intricacies of the laws of nature. The main point is that the evolution of mind would be tied into the evolutionary process by virtue of the mind's dynamical effects on the behavior of the organism with which it is associated.

It is important that the Quantum Zeno Effect of a rapid sequence of Process I events associated with a projection operator  $P$  would tend to keep the original state  $PSP$  confined to states of the form  $PXP$ , but that the factor  $X$  would evolve in a normal way. In other words, within the branch of the universe picked out by the constant or slowly changing sequence of projection operators  $P$  the normal laws of motion would tend to operate, apart from the fixed (or slowly changing) constraint that keeps the idea (focus of attention) associated with  $P$  on place. Without the Quantum Zeno Effect, which is a strictly quantum effect having no classical analog, the system

would tend to evolve in a very different way: there would be rapid transitions from the part of the space of possibilities associated with the state of attention associated with  $P$ , to the complementary part of the space of possibilities. Thus, by virtue of the Quantum Zeno Effect, a focus of attention associated with a projection operator  $P$  could be sustained in the face of strong mechanical disruptive tendencies while the mechanical processing *within* the subspace specified by that fixed focus of attention proceeds rather normally

This capacity of mental intention to keep attention focused in the face of natural distractions could produce large deviations in the behavior of a quantum agent from his classical zombie (i.e., nonconscious) counterpart. If by mental effort the “free choices” associated Process I can be caused to produce a rapid repetition of the Process I interventions with the same or slowly changing  $P$ , then the activity of the brain activity would be channeled by this mental effort!

It is worth mentioning that the Quantum Zeno Effect applies even to a state  $S$  that is completely diagonal (i.e., whose off-diagonal elements  $S(i,j)$ , for  $i$  different from  $j$ , are all zero). This is important because there is a very powerful effect called “environmental decoherence” that tends to reduce  $S$  to nearly diagonal form; that is, to a form where  $S(l,l')$  is appreciable only if the two location variables  $l$  and  $l'$  are nearly equal. This makes the state closer to a classical kind of state. But the state still retains its smeared-out cloudlike quality along the diagonal, and this cloud normally moves around. Even though the state has become, by virtue of the environmental decoherence effect, somewhat closer to classical, the Quantum Zeno Effect holds with unabated strength: the transitions out of the ‘Yes’ subspace of states into the ‘No’ subspace are still inhibited by a rapid sequence of similar Process I events .

## 6. KNOWLEDGE, INFORMATION, AND ENTROPY

The book *John von Neumann and the Foundations of Quantum Physics* contains a fascinating and informative article written by Eckehart Kohler entitled “Why von Neumann Rejected Carnap’s Dualism of Information Concept.” The topic is precisely the core issue before us: How is knowledge connected to physics? Kohler illuminates von Neumann’s views on this subject by contrasting them to those of Carnap.

Rudolph Carnap was a distinguished philosopher, and member of the Vienna Circle. He was in some sense a dualist. He had studied one of the central problems of philosophy, namely the distinction between *analytic* statements and *synthetic* statements. (The former are true or false by virtue of a specified set of rules held in our minds, whereas the latter are true or false by virtue their concordance with physical or empirical facts.) His conclusions had led him to the idea that there are two different domains of truth, one pertaining to logic and mathematics and the other to physics and the natural sciences. This led to the claim that there are “Two Concepts of Probability,” one logical the other physical. That conclusion was in line with the fact that philosophers were then divided between two main schools as to whether probability should be understood in terms of abstract idealizations or physical sequences of outcomes of measurements. Carnap’s bifurcations implied a similar division between two different concepts of information, and of entropy.

In 1952 Carnap was working at the Institute for Advanced Study in Princeton and about to publish a work on his dualistic theory of information, according to which epistemological concepts like information should be treated separately from physics. Von Neumann, in private discussion, raised objections, and Pauli later wrote a forceful letter, asserting that “I am quite strongly opposed to the position you take.” Later he adds “I am indeed concerned that the confusion in the area of the foundations of statistical mechanics not grow further (and I fear very much that a publication of your work in its present form would have this effect).”

Carnap’s view was in line with the Cartesian separation between a domain of real objective physical facts and a domain of ideas and

concepts. But von Neumann's view, and also Pauli's, linked the probability that occurred in physics, in connection with entropy, to *knowledge*, in direct opposition to Carnap's view that epistemology (considerations pertaining to knowledge) should be separated from physics. The opposition of von Neumann and Pauli significantly influenced the publication of Carnap's book.

This issue of the relationship of knowledge to physics is the central question before us, and is in fact the core problem of all philosophy and science. In the earlier chapters I relied upon the basic insight of the founders of quantum theory, and upon the character of quantum theory as it is used in actual practice, to justify the key postulate that Process I is associated with knowing, or feeling. But there is also an entirely different line of justification of that connection developed in von Neumann's book, *Mathematical Foundations of Quantum Mechanics*. This consideration, which strongly influenced his thinking for the remainder of his life, pertains to the second law of thermodynamics, which is the assertion that entropy (disorder, defined in a precise way) never decreases.

There are huge differences in the quantum and classical workings of the second law. Von Neumann's book discusses in detail the quantum case, and some of those differences. In one sense there is no nontrivial objective second law in classical physics: a classical state is supposed to be objectively well defined, and hence it always has probability one. Consequently, the entropy is zero at the outset and remains so forevermore. Normally, however, one adopts some rule of "coarse graining" that destroys information and hence allows probabilities to be different from unity, and then embarks upon an endeavor to deduce the laws of thermodynamics from statistical considerations. Of course, it can be objected that the subjective act of choosing some particular coarse graining renders the treatment not completely objective, but that limited subjective input seems insufficient to warrant the claim that physical probability is closely tied to knowledge.

The question of the connection of entropy to the *knowledge and actions of an intelligent being* was, however, raised in a more incisive form by Maxwell, who imagined a tiny "demon" to be stationed at a small doorway between two large rooms filled with gas. If this agent

could distinguish different species of gas molecules, or their energies and locations, and slide a frictionless door open or closed according to which type of molecule was about to pass, he could easily cause a decrease in entropy that could be used to do work, and hence to power a perpetual motion machine, in violation of the second law.

This paradox was examined Leo Szilard, who replaced Maxwell's intelligent "demon" by a simple idealized (classical) physical mechanism that consumed no energy beyond the apparent minimum needed to 'recognize and responded differently to' a two-valued property of the gas molecule. He found that this rudimentary process of merely 'coming to know and respond to' the two-valued property transferred entropy from heat baths to the gaseous system in just the amount needed to preserve the second law. Evidently nature is arranged so that what we conceive to be the purely intellectual process of coming to know something, and acting on the basis of that knowledge, is closely linked to the probabilities that enter into the constraints upon physical processes associated with entropy.

Von Neumann describes a version of this idealized experiment. Suppose a single molecule is contained in a volume  $V$ . Suppose an agent comes to know whether the molecule lies to the left or to the right of the center line. He is then in the state of being able to order the placement of a partition/piston at that line and to switch a lever either to the right or to the left, which restricts the direction in which the piston can move. This causes the molecule to drive the piston slowly to the right or to the left, and transfer some of its thermal energy to it. If the system is in a heat bath then this process extracts from the heat bath an amount 'log 2' of entropy (in natural units). Thus the *knowledge* of which half of the volume the molecule was in is converted into a decrement of "log 2" units of entropy. In von Neumann's words, "we have exchanged our knowledge for the entropy decrease  $k \log 2$ ." ( $k$  is the natural unit of entropy.)

What this means is this: When we conceive of an increase in the "knowledge possessed by some agent" we must not imagine that this knowledge exists in some ethereal kingdom, apart from its physical representation in the body of the agent. Von Neumann's analysis shows that the change in knowledge represented by Process I is quantitatively tied to the probabilities associated with entropy.

Among the many things shown by von Neumann are these two:

- (1) The entropy of a system is unaltered when the state of that system is evolving solely under the governance of Process II.
- (2) The entropy of a system is never decreased by any Process I event.

The first result is analogous to the classical result that if an objective “probability” were to be assigned to each of a countable set of possible classical states, and the system were allowed to evolve in accordance with the classical laws of motion then the entropy of that system would remain fixed.

The second result is a nontrivial quantum second law of thermodynamics. Instead of coarse graining one has Process I, which in the simple ‘Yes-No’ case converts the prior system into one where the question associated with the projection operator  $P$  has a definite answer, but only the *probability* associated with each possible answer is specified, not an answer itself.

One sees, therefore, why von Neumann rejected Carnap’s attempt to divorce knowledge from physics: large tracts in his book were devoted to establishing their marriage. That work demonstrates the quantitative link between the increment of knowledge or information associated with a Process I event and the probabilities connected to entropy. This focus on Process I allowed him to formulate and prove a quantum version of the second law. In the quantum universe the rate of increase of entropy would be determined not by some imaginary and arbitrary coarse graining rule, but by the number and nature of objectively real Process I events.

Kohler discusses another outstanding problem: the nature of mathematics. At one time mathematics was imagined to be an abstract resident of some immaterial Platonic realm, independent in principle from the brains and activities of those who do it. But many mathematicians and philosophers now believe that the process of doing mathematics rests in the end on mathematical intuitions, which are essentially aesthetic evaluations.

Kohler argues that von Neumann held this view. But what is the origin or source of such aesthetic judgments?

Roger Penrose based his theory of consciousness on the idea that mathematical insight comes from a Platonic realm. But according to the present account each such illumination, like any other experience, is represented in the quantum description of nature as a picking out of an organized state in which diverse brain processes act together in an harmonious state of mutual support. A mathematical illumination is a grasping of an *aesthetic* quality of order in the quantum state of the agent's brain/body. But apparently every experience of any kind is fundamentally like this: it is a Process I grasping of a state of order.

This notion that each Process I event is a felt grasping of a state in which various sub-processes act in concert provides a foundation for answering in a uniform way many outstanding philosophical and scientific problems. For example, it provides a foundation for a solution to a basic issue of neuroscience, the so-called "binding problem". It is known that diverse features of a visual scene, such as color, location, size, shape, etc. are processed by separate modules located in different regions of the brain. This understanding of the Process I event makes the felt experience a grasping of a non-discordant quasi-stable mutually supportive combination of these diverse elements as a unified whole. To achieve maximal organizational impact this event should provide the conditions for a rapid sequence of re-enactments of itself. Then this conception of the operation of von Neumann's process I provides also an understanding of the capacity of an agent's thoughts to control its bodily behavior. The same conception of Process I provides also a basis for understanding both artistic and mathematical creativity, and the evolution of consciousness in step with the biological evolution of our species. These issues all come down to the problem of the connection of knowings to physics, which von Neumann's treatment of entropy ties to Process I.

Kohler quotes an interesting statement of von Neumann, but then draws from it conclusions about von Neumann's views that go far beyond what von Neumann actually said.

Von Neumann points out that in classical mechanics one can solve the problem of motion either by solving differential equations (the local causal mechanistic approach) or by using a global least action (or some other similar) approach. This latter method can be viewed as “teleological” in the sense that if initial and final conditions are specified then the principle of least action specifies the path between them. He goes on to say that he is:

“not trying to be facetious about the importance of keeping teleological principles in mind when dealing with biology; but I think one hasn’t started to understand the problem of their role in biology until one realizes that in mechanics, if you are just a little bit clever mathematically, your problem disappears and becomes meaningless. And it is perfectly possible that if one understood another area then the same thing might happen.”

The pertinent “other area” is psychology, or the problem of mind.

The first point is that von Neumann’s statement is very cautious: he says that it is “perfectly *possible* that *if* one understood another area the same thing *might* happen.” There are three weak links: “possible”, “if”, and “might.”

Kohler’s conclusion is far less cautious. He follows the above quotation with the assertion:

“Here von Neumann warns biologists against overstressing goal-directed activity since this can always be reformulated *causally*.”

Von Neumann said no such thing. He merely points out that in classical mechanics certain global least action principles are equivalent to local causal mechanistic rules. That falls far short of claiming that *all* goal-directed activity can be expressed in least-action terms, or that in *non-classical* cases such a least-action formulation would necessarily be equivalent to a local causal mechanism. Von Neumann recognizes this as a possibility, not a necessity.

In quantum physics the Process II part of the dynamics is derived from the quantization of the classical law. Hence it might be

contended that *for this Process II part of the dynamics* an equivalence holds between “teleological” and “causal” formulations. But the connection to mind involves Process I. It is far from obvious that the equivalence found in classical mechanics will carry over to Process I. In the first place, Process I involves non-local operators  $P$ , and that alone would appear to block reduction to local causation. In the second place, Process I drops out of the dynamics when one goes to the classical limit, which is the limit in which all effects involving Planck’s constant are neglected. Hence Process I is, in this sense, non classical or anti-classical. Hence there is no reason to believe that equivalences occurring in classical physics will carry over to Process I. Such a connection “might possibly” hold, but it is surely not required to hold by anything we know today.

Kohler goes on to state that:

“Based on his general approach, one may say von Neumann was a psycho-physical reductionist who thought human intelligence could in principle be presented and explained on a physical level --- in particular, neurologically, in terms of nerve nets. Between the physiology of nerves and the physics of computer devices von Neumann recognized no difference in functional capacity.”

That last statement seems tremendously at odds with the conclusions of von Neumann’s final work, “The Computer and the Brain,” which emphasized the huge differences between brains and computers. But, that point aside, the fact that von Neumann did much work on classically describable computers does not imply that he was committed to the view that *human intelligence* could be understood in classical terms. Von Neumann may indeed have not excluded that possibility, but I doubt that any statement of his shows him to be committed to the position that human intelligence, and, more importantly, his Process I, can be explained in local mechanistic terms. The statement quoted above certainly fails to justify such a conclusion.

## 7. RECENT VIEWS.

A tremendous burgeoning of interest in the problem of consciousness has occurred during the past few years. The grip of the behaviorists who sought to banish consciousness from science has finally been broken. This shift is ratified by the recent appearance of a special issue of Scientific American entitled "The Hidden Mind." The lead article, written by Antonio Damasio, begins with the assertion: "At the start of the new millennium, it is apparent that one question towers above all others in the life sciences: How does the set of processes we call mind emerge from the activity of the organ we call brain?" He notes that some thinkers "believe the question to be unanswerable in principle" while "For others, the relentless and exponential increase in knowledge may give rise to the vertiginous feeling that no problem can resist the assault of science if *only the science is right* and the techniques are powerful enough." (my emphasis) He notes that "The naysayers argue that exhaustive compilation of all these data (of neuroscience) adds up to *correlates* of mental states but to nothing resembling *an actual mental state*." (his emphasis) He adds that: "In fact, the explanation of the physics related to biological events is still incomplete" and states that "the finest level of description of mind ... might require explanation at the quantum level." Damasio makes his own position clear: "I contend that the biological processes now presumed to correspond to mind in fact *are* mind processes and will be seen to be so when understood in sufficient detail."

With "biological processes" understood to be quantum processes, including the key Process I, I agree that mind processes are biological brain processes. The point is that biological brain processes demand, for the reasons described in Chapter 4, the application of quantum physics, and that makes feelings, for the reasons explained in Chapters 5 and 6, critical and non-redundant components of brain dynamics.

The possibility that quantum physics might be relevant to the connection between conscious process and brain process was raised also by Dave Chalmers, in his article *The Puzzle of Consciousness*. However, he effectively tied that possibility to a proposal put forth by Roger Penrose, and, faulting that particular approach, rejected the general idea.

The deficiency of Penrose's approach identified by Chalmers is that it fails to bring in consciousness: it is about certain brain processes that may be related to consciousness, but "...the theory is silent about how these processes might give rise to conscious experience. Indeed, the same problem arises with any theory of consciousness based only on physical processing." That final conclusion is based, however, on the presumption that physical brain processes can be described in a way that leaves experiences out. But, for the reasons described, Process I, hence experiences, plays an irreplaceable dynamical role in physical brain processing.

Chalmers goes on to expound upon the "explanatory gap" between theoretical understanding of the behavioral and functional aspects of brain process and an explanation of how and why the performance of those functions should be accompanied by conscious experience. However, the notion that such a "gap" exists depends upon the presumption that a valid understanding or conception of physical brain behavior can be divorced from its connection to the associated conscious experiences. But the notion that such a separation is possible arises only from the inadequate-in-this-regard classical model.

The confounding of reality itself with the caricature of it suggested by the work of Descartes and Newton has derailed the philosophy of science, the philosophy of mind, moral philosophy, and aesthetics for more than three centuries, by presenting it with an irresolvable dilemma based on a conception of nature that is profoundly wrong at precisely the critical point. This flawed view still retains its blinding effect on the thinking of even those philosophers who absolutely reject that dualistic view. For example, Daniel Dennett, one of the most out-spoken critics of classical Cartesian dualism, says that his own thinking rested on the idea that "a brain was always going to do what it was caused to do by current, local, mechanical circumstances." But by making that judgment he tied his thinking to *the physical half of Cartesian/Newtonian dualism*, or its child, classical physics, and thus was forced in his book "Explaining Consciousness" to leave consciousness out, as he himself admits, but tries to justify, at the end. By thus accepting the fundamentally erroneous classical-physics understanding of brain processes,

instead of the view offered by modern science, Dennett cuts himself off from any possibility of validly explaining consciousness.

Many important features of the von Neumann approach being described here can be brought out by contrasting them with the contrary properties of Penrose's proposal. The first key difference is that Penrose does not introduce the von Neumann Process I, which is essential to von Neumann quantum theory. Penrose uses instead the Process III: the eradication of one or the other of the two branches; State Vector Reduction, which he calls R. This difference is crucial! State Vector Reduction, which Penrose *does* use, brings in the perhaps unnecessary global non-locality, whereas Process I, which he *does not* use, at least explicitly, accounts for the causal effect of the intentional effort of the agent upon on his brain.

A second essential difference between the present proposal and that of Penrose, and his collaborator Stuart Hameroff, is that their theory depends on establishing macroscopic quantum coherence over an extended portion of the brain, whereas the theory being described here does not. Most physicists deem it highly unlikely that such large-scale coherence could be sustained in a warm, wet, living brain.

A third difference is that their theory depends on the complex question of quantum gravity, which is currently not under good theoretical control, whereas the theoretical ideas that are the basis of the present approach are the fundamental mathematical principles of quantum theory, which, thanks to the work of John von Neumann, are under much better control.

The fourth difference is that the justification that Penrose gives for believing that quantum theory has something to do with human consciousness is a very much disputed argument that claims to deduce from (1), the fact that mathematicians construct proofs that they believe to be valid, and (2), some deep mathematical results due to Kurt Godel, the conclusion that conscious thought must involve quantum theory. But in the von Neumann approach the relevance of consciousness arises not from any such complex argument, but rather directly from its connection to Process I, which is a basic feature of orthodox quantum theory.

The fifth difference is the fact, already emphasized by Chalmers, that Penrose's theory of consciousness turns out to be about a conceivable neural correlate of consciousness, but is silent about how that brain activity might give rise to conscious experiences, whereas the present work is directly about the relationship of brain processes to conscious experiences.

Francis Crick and Christof Koch begin their essay *The Problem of Consciousness* with the assertion: "The overwhelming question in neurobiology today is the relationship between the mind and the brain." But after a brief survey of the difficulties in getting an answer they conclude that "Radically new concepts may indeed be needed---recall the modifications in scientific thinking forced on us by quantum mechanics. The only sensible approach is to press the experimental attack until we are confronted with dilemmas that call for new ways of thinking."

However, the two cases are extremely dissimilar. The switch to quantum theory was forced upon us by the fact that we had a very simple system, consisting of one proton and one electron, that was so simple that it could be exactly solved by the methods of classical physics, but the calculated answer did not agree with the empirical results. There was no conceptual problem. It was rather that precise computations were possible, but gave wrong answers. Here the problem is reversed: precise calculations of the dynamical processes associated with conscious experiences are not yet possible, and hence have not revealed any mismatch between theory and experiment, but the *concepts of classical physics* that most neurobiologists want to use are clearly inadequate: they lack the conceptual ingredients needed to account for conscious experience. Dave Chalmers recognizes this conceptual difficulty, and concludes that experimental work by neurobiologists is not by itself sufficient to resolve of *The Puzzle of Conscious Experience*: also needed are better concepts. He suggests that the stuff of the universe might be *information*, but then rejects the replacement of classical physical theory, which is based on material substance, by quantum theory, which builds (its conception of) nature out of a non-substantive stuff that can be characterized as information encoded in a space-time non-material structure.

John Searle is perhaps the strongest contemporary voice calling for a forthright acknowledgement of both the existence of the subjective realities that *are* the experiential qualities, and also the need to explain them, rather than trying to explain them away. His most recent views mesh well with the quantum approach developed here.

I shall use as my source Searle's article in the Journal of Consciousness Studies, which is based on his talk at the Tucson 2000 conference on Consciousness. This presentation seems to me to represent his best effort to come to grips with the problem.

Searle reiterates his longtime themes:

1. Consciousness is a real biological phenomenon.
2. It consists of inner, qualitative, subjective, unified states of sentience, awareness, thoughts and feelings.
3. This unified field of conscious subjective awareness is not reducible to any third-person phenomena.
4. All of our conscious states are caused by lower-level neuronal processes in the brain.
5. All of our conscious states are themselves features of the brain.

If one were to accept the classical-physics conception of the brain then there would appear to be a conflict between claims 3 and 5. For if a brain were a conglomeration of particles, which, as the objective elements of nature are third-person entities, and conscious states are features of these conglomerations, as asserted by claim 5, then consciousness seems to be reduced to third-person phenomena, in violation of claim 3. However, if one accepts the quantum idea that the states of consciousness characterized in properties 1, 2, and 3, above, are first-person subjective features of the brain, which is an informational structure that combines distinct first-person and third-person informational features, then this conflict is resolved. Searle's position needs quantum theory in order to become internally consistent.

Later on, Searle introduces "psychological processes" by observing that people sometimes give 'reasons' for acting as they do. But he notes that these 'reasons' are not always conclusive, or sufficient to entail the actions they promote. He wishes to consider the possibility

that although the psychological processes may be indeterministic, the underlying “neurobiological process” is deterministic. He then says that psychological indeterminism with neurobiological determinism---

“is intellectually unsatisfying because it is a modified form of epiphenomenalism. It says that the psychological processes of decision making really do not matter. The entire process is deterministic at the bottom level, and the idea that the top level has an element of freedom is simply a systematic illusion. ... The bodily movements would be exactly the same regardless of how these processes occurred.

“Maybe that is how it will turn out, but if so the hypothesis seems to me to run against everything we know about evolution. It would have the consequence that the incredibly elaborate, complex, sensitive and ---above all---biologically expensive system of human and animal conscious rational decision-making would actually make no difference whatever to the life and survival of the organism. Epiphenomenalism is a possible thesis, but it is absolutely incredible, and if we seriously accept it, it would make a change in our world view, that is, in our conception of our relations to the world, more radical than any previous change, including the Copernican Revolution, Einsteinian relativity theory and quantum theory.”

The sort of epiphenomenal consciousness that Searle is considering, and finds incredible, is what necessarily arises from a classical-physics conception of the brain. But quantum theory gives consciousness a causal power that is outside the control of the bottom-level local deterministic laws that are the quantum counterparts of the classical laws of motion. The causal power of consciousness arises from the way that consciousness fills a *causal gap* in those bottom-level laws. This lacuna is filled in by conscious causal agents, acting via the ‘top-down’ Process I.

Semir Zeki, a leading neuroscientist in the study of the diverse brain processes connected to vision, writes about the process of abstraction associated with the creation of works of art, analyzing the treatments of “love” in the poetry of Dante, the sculptures of Michelangelo, and the opera *Tristan and Isolde* by Wagner. He focuses on the abstracting powers of the various separate processing

modules but says: “There must therefore be some other process that unifies and binds what these different areas have processed, a problem that is currently under study. The point that I emphasize here is that the unification and binding come after the abstractive processes, which constitute the first step in the knowledge-acquiring system.”

This “process that unifies and binds what ... diverse areas have processed” is an activity that pervades and characterizes our experiential lives. It can be understood as a sequence of graspings of brain states having aesthetically felt qualities of coherent harmonious equilibrium. These graspings produce bindings of the diverse elements of visual scenes, mathematical intuitions, artistic creativity, the causal power of mental effort to influence bodily behavior, and the development of animal consciousness in conjunction with the evolution of species. I shall consider next some supporting evidence from psychology for the existence, in human agents, of a process of this kind that conforms to the features of Process I demanded by orthodox quantum theory.

## 8. PSYCHO-PHYSICAL THEORY AND “WILL.”

I have concentrated so far on what is basically new: on the crucial difference between classical physics and quantum physics that allows our thoughts to be an essential player in the causal description of brain process. This new element needs to be placed in the context of what I take to be otherwise a fairly standard psycho-physical theory, perhaps the orthodox theory to the extent that any such thing exists.

As already mentioned, I follow William James and take all conscious experiences to be essentially “feelings” of one kind or another. Experiencing a major chord “feels different” from experiencing a minor chord. The exhilarating experiencing of a rapid piano run up the scale feels different from the tip-toe-y feeling of a lightly fingered sequence of high notes, or the satisfying feeling of the final chord of a work of Beethoven or Wagner. Einstein described the feeling of his theoretical reflections in terms of muscular feelings, and a mathematician knows his proof is valid because of a deep feeling that all bases have been well covered: there is no feeling of discord, or incompleteness, or incursion of doubt.

A person’s thoughts are dynamically linked to patterns of brain activity that are his brain’s representations of his physical body and its relationship to the world around him. Called the body-world schema, this momentary brain representation is, during wakeful periods being continually updated by the brain on the basis of its interpretation of clues provided by the sensory apparatus, and it is closely tied into his bodily actions and their sensed connections to the outer world. His actions are controlled by activating patterns in the body-world schema, and he learns through experience the relationship between his felt intentions and the subsequent feed-back in terms of sensed experiences. The body-world schema is the intermediary physical link. The dynamical interplay between these intentional acts, the body-world schema, and sensory feedback tunes the connection between mind and brain, and links the felt quality of the intentional act to a mental image of the intended consequences.

A person’s experiential life is a stream of conscious experiences. The person’s experienced ‘self’ is *part* of this stream of consciousness: it is not an extra thing that is outside or apart from the stream. In

James's words "*thought is itself the thinker*, and psychology need not look beyond." The "self" is a slowly changing "fringe" part of the stream of consciousness. It provides a background for the central focus.

The physical brain, evolving mechanically in accordance with the local deterministic Process II does most of the work, without the intervention of Process I. It does its job of creating, on the basis of its interpretation of the clues provided by the senses, a suitable response. But, due to the wave nature of its component parts, the brain necessarily generates an amorphous mass of overlapping and conflicting templates for action, formulated in terms of possible structures for the body-world schema. Process I selects from among these possibilities, on the basis of high-level coherency and stability criteria that access the entire structure of the brain *as a whole*, the possible state PSP, which is the 'Yes' branch of the state  $S' = \text{PSP} + (\text{I-P})(\text{S(I-P)})$  created by Process I.

Intentionality acts by controlling attention. Intention activates a Process I event that grasps a state PSP in which attention is focused on actualizing the intended state. The corresponding physical state is built around a projected body-world schema. The body-world schema is created by interaction between intention and feed-back, and a sustained persistence of a projected body-world schema tends to initiate the appropriate motor actions, monitoring actions, and follow-up events.

The phenomena of "will" is understood as a condition in which an initial Process I event leads to the occurrence of a very rapid sequence of follow-up events defined by very nearly the same P: a "mental effort" causes a rapid repetition of Process I events with almost identical projection operators P. Then the quantum equations of motion have the effect of preventing any transitions of 'Yes' states to 'No' states. The state is held in a state of the form  $PXP$ , with fixed or slowly changing P, in spite of all sorts of disruptive and distracting mechanical influences that would otherwise cause a wandering of attention. The mental effort is thereby causing a large deviation of brain activity from what it would otherwise be. Mental effort is importantly influencing brain process.

Does this theory of the connection between mind and brain explain anything?

This theory was already in place when a colleague, Dr. Jeffrey Schwartz, brought to my attention some passages from ``Psychology: The Briefer Course'', written by William James. In the final section of the chapter on Attention James writes:

``I have spoken as if our attention were wholly determined by neural conditions. I believe that the array of things we can attend to is so determined. No object can catch our attention except by the neural machinery. But the amount of the attention which an object receives after it has caught our attention is another question. It often takes effort to keep mind upon it. We feel that we can make more or less of the effort as we choose. If this feeling be not deceptive, if our effort be a spiritual force, and an indeterminate one, then of course it contributes coequally with the cerebral conditions to the result. Though it introduce no new idea, it will deepen and prolong the stay in consciousness of innumerable ideas which else would fade more quickly away. The delay thus gained might not be more than a second in duration---but that second may be critical; for in the rising and falling considerations in the mind, where two associated systems of them are nearly in equilibrium it is often a matter of but a second more or less of attention at the outset, whether one system shall gain force to occupy the field and develop itself and exclude the other, or be excluded itself by the other. When developed it may make us act, and that act may seal our doom. When we come to the chapter on the Will we shall see that the whole drama of the voluntary life hinges on the attention, slightly more or slightly less, which rival motor ideas may receive. ..."

In the chapter on Will, in the section entitled "Volitional effort is effort of attention" James writes:

"Thus we find that we reach the heart of our inquiry into volition when we ask by what process is it that the thought of any given action comes to prevail stably in the mind."

and later

"The essential achievement of the will, in short, when it is most 'voluntary,' is to attend to a difficult object and hold it fast before the mind. ... Effort of attention is thus the essential phenomenon of will."

Still later, James says:

"Consent to the idea's undivided presence, this is effort's sole achievement."...

"Everywhere, then, the function of effort is the same: to keep affirming and adopting the thought which, if left to itself, would slip away."

This description of the effect of mind on the course of mind-brain process is remarkably in line with what had been proposed independently from purely theoretical consideration of the quantum physics of this process. The connections specified by James are explained on the basis of the same dynamical principles that had been introduced by physicists to explain atomic phenomena. Thus the whole range of science, from atomic physics to mind-brain dynamics, is brought together in a single rationally coherent theory of an evolving cosmos that consists of a physical reality that is constituted not of matter but of tendencies for Process I events to occur.

Much experimental work on attention and effort has occurred since the time of William James. That work has been hampered by the apparent nonexistence of any physical theory that rationally explains

how our conscious experiences could influence activities in our brains. The behaviorist approach, which dominated psychology during the first half of the twentieth century, and which essentially abolished in this field the use not only of introspective data but also of the very concept of consciousness, was surely motivated in part by the fact that consciousness was excluded from any role in brain dynamics by the physics of the preceding century

The admitted failure of the behaviorist programs led to the rehabilitation of "attention" during the early fifties, and many hundreds of experiments have been performed during the past fifty years for the purpose of investigating empirically those aspects of human behavior that we ordinarily link to our consciousness.

Harold Pashler's 1998 book "The Psychology of Attention" [32] describes a great deal of this empirical work, and also the intertwined theoretical efforts to understand the nature of an information-processing system that could account for the intricate details of the empirical data. Two key concepts are the notions "Attention" and of a processing "Capacity". The former is associated with an internally directed selection between different possible allocations of the available processing "Capacity". A third concept is "Effort", which is linked to incentives, and to reports by subjects of "trying harder".

Pashler organizes his discussion by separating perceptual processing from post-perceptual processing. The former covers processing that, first of all, identifies such basic physical properties of stimuli as location, color, loudness, and pitch, and, secondly, identifies stimuli in terms of categories of meaning. The post-perceptual process covers the tasks of producing motor actions and cognitive action beyond mere categorical identification. Pashler emphasizes [p. 33] that "the empirical findings of attention studies specifically argue for a distinction between perceptual limitations and more central limitations involved in thought and the planning of action." The existence of these two different processes, with different characteristics, is a principal theme of Pashler's book [p. 33, 263, 293, 317, 404].

In the quantum theory of mind-brain being described here there are two separate processes. First, there is the unconscious mechanical brain process governed by the Schroedinger equation. As discussed

at length in my earlier book, *Mind, Matter, and Quantum Mechanics*, this brain processing involves dynamical units that are represented by complex patterns of neural activity (or, more generally, of brain activity) that are "facilitated" by use, and are such that each unit tends to be activated as a whole by the activation of several of its parts. The activation of various of these complex patterns by cross referencing, coupled to feed-back loops that strengthen or weaken the activities of appropriate processing centers, appears to explain the essential features of the mechanical part of the dynamics.

The function of the brain is to create and direct courses of action appropriate to the circumstances in which the organism finds itself. Accordingly, the brain ought to create a template for a possible plan of action. Detailed examination of the quantum uncertainties associated the motion in nerve terminals of incoming calcium ions from the ion channels to the triggering sites for the release of vesicles of neurotransmitter entail [MM&QM, p.152] that a host of different possibilities will emerge. This mechanical phase of the processing already involves some selectivity, because of the enhancing and inhibiting feedback loops. But the essential point is that the evolution of the brain according to the Schrodinger equation *must* generate not just one single template for action, but a host of alternative possibilities. Hence the action of the second process, von Neumann's Process I must come into play in order to select what actually happens from the continuum of alternative possibilities generated by the mechanical aspect of the full quantum dynamics. But Process I involves the element of freedom that feeds into the Quantum Zeno Effect.

This conception of brain dynamics seems to accommodate all of the perceptual aspects of the data described by Pashler. But it is the high-level processing, which is more closely linked to our active mentally controlled conscious thinking, that is of prime interest here. The data pertaining to this second process is the focus of part II of Pashler's book.

Mental intervention has, according to the quantum-physics-based theory described here, several distinctive characteristics. It consists of a sequence of discrete events each of which consents to an integrated course of action presented by brain. The rapidity of these

events can be increased with effort. Effort-induced speed-up of the rate of occurrence of these events can, by means of the quantum Zeno effect, keep attention focussed on a task. Between 100 and 300 msec of consent seem to be needed to fix a plan of action.

Effort can, by increasing the number of events per second, increase the mental input into brain activity. Each conscious event picks out from the multitude of quasi-classical possibilities that comprise the quantum brain the sub-ensemble that is compatible with the conscious experience.

The correspondence between the mental event and the associated physical event is this: the physical event reduces the prior physical ensemble of alternative possibilities to the sub-ensemble compatible with the mental event. This connection constitutes the core postulate of Copenhagen quantum theory: the physical event reduces the prior state of the system to the part of it that is compatible with the experience of the observer.

Examination of Pashler's book shows that this quantum-physics-based theory accommodates naturally all of the complex structural features of the empirical data that he describes. He emphasizes [p. 33] a specific finding: strong empirical evidence for what he calls a central processing bottleneck associated with the attentive selection of a motor action. This kind of bottleneck is what the quantum-physics-based theory predicts: the bottleneck is precisely the single linear sequence of mind-brain quantum events that von Neumann quantum theory is built upon.

Pashler [p. 279] describes four empirical signatures for this kind of bottleneck, and describes the experimental confirmation of each of them. Much of part II of Pashler's book is a massing of evidence that supports the existence of a central process of this general kind.

This bottleneck is not automatic within classical physics. A classical model could easily produce simultaneously two responses in different modalities, say vocal and manual, to two different stimuli arriving via two different modalities, say auditory and tactile. The two processes could proceed via dynamically independent routes. Pashler [p. 308] notes that the bottleneck is undiminished in split-brain patients

performing two tasks that, at the level of input and output, seem to be confined to different hemispheres.

The queuing effect for the mind-controlled motor responses does not exclude interference between brain processes that are similar to each other, and hence that use common brain mechanisms. Pashler [p. 297] notes this distinction, and says ``the principles governing queuing seem indifferent to neural overlap of any sort studied so far."

The important point here is that there is in principle, in the quantum model, an essential dynamical difference between, on the one hand, the unconscious processing carried out by the Schroedinger evolution, which generates via a local process an expanding collection of classically implementable possible courses of action, and, on the other hand, the process associated with the sequence of conscious events that constitutes a stream of consciousness. The former are not limited by the queuing effect, because all of the possibilities develop in parallel, whereas the latter do form elements of a single queue. The experiments cited by Pashler all appear to support this clear prediction of the quantum approach.

An interesting experiment mentioned by Pashler involves the simultaneous tasks of doing an IQ test and giving a foot response to rapidly presented sequences of tones of either 2000 or 250 Hz. The subject's mental age, as measured by the IQ test, was reduced from adult to 8 years. [p. 299] This result supports the prediction of quantum theory that the bottleneck pertains both to `intelligent' behavior, which requires conscious processing, and to selection of motor response.

Another interesting experiment showed that, when performing at maximum speed, with fixed accuracy, subjects produced responses at the same rate whether performing one task or two simultaneously: the limited capacity to produce responses can be divided between two simultaneously performed tasks. [p. 301]

Pashler also notes [p. 348] that ``Recent results strengthen the case for central interference even further, concluding that memory retrieval is subject to the same discrete processing bottleneck that prevents simultaneous response selection in two speeded choice tasks."

In the section on "Mental Effort" Pashler reports that "incentives to perform especially well lead subjects to improve both speed and accuracy", and that the motivation had "greater effects on the more cognitively complex activity". This is what would be expected if incentives lead to effort that produces increased rapidity of the events, each of which injects into the physical process, via quantum selection and reduction, bits of control information that reflect mental evaluation.

Studies of sleep-deprived subjects suggest that in these cases "effort works to counteract low arousal". If arousal is essentially the rate of occurrence of conscious events then this result is what the quantum model would predict.

Pashler notes that "Performing two tasks at the same time, for example, almost invariably... produces poorer performance in a task and increases ratings in effortfulness." And "Increasing the rate at which events occur in experimenter-paced tasks often increases effort ratings without affecting performance". "Increasing incentives often raises workload ratings and performance at the same time." All of these empirical connections are in line with the general principle that effort increases the rate of conscious events, each of which inputs a mental evaluation and a selection or focussing on a course of action, and that this resource can be divided between tasks.

Additional supporting evidence comes from the studies of the effect of the conscious process upon the storage of information in short-term memory. According to the physics-based theory, the conscious process merely actualizes a course of action, which then develops automatically, with perhaps some occasional monitoring. Thus if one sets in place the activity of retaining in memory a certain sequence of stimuli, then this activity can persist undiminished while the central processor is engaged in another task. This is what the data indicate.

Pashler remarks that "These conclusions contradict the remarkably widespread assumption that short-term memory capacity can be equated with, or used as a measure of, central resources." [p.341] In the theory outlined here short-term memory is stored in patterns of brain activity, whereas consciousness is associated with the selection

of a sub-ensemble of quasi-classical states. This distinction seems to account for the large amount of detailed data that bears on this question of the connection of short-term-memory to consciousness. [p.337-341]

Deliberate storage in, or retrieval from, long-term memory requires focussed attention, and hence conscious effort. These processes should, according to the theory, use part of the limited processing capacity, and hence be detrimentally affected by a competing task that makes sufficient concurrent demands on the central resources. On the other hand, "perceptual" processing that involves conceptual categorization and identification without conscious awareness should not interfere with tasks that do consume central processing capacity. These expectations are what the evidence appears to confirm: "the entirety of...front-end processing are modality specific and operate independent of the sort of single-channel central processing that limits retrieval and the control of action. This includes not only perceptual analysis but also storage in STM (short term memory) and whatever may feed back to change the allocation of perceptual attention itself." [p. 353]

Pashler describes a result dating from the nineteenth century: mental exertion reduces the amount of physical force that a person can apply. He notes that "This puzzling phenomena remains unexplained." [p. 387]. However, it is an automatic consequence of the physics-based theory: creating physical force by muscle contraction requires an effort that opposes the physical tendencies generated by the Schroedinger equation. This opposing tendency is produced by the quantum Zeno effect, and is roughly proportional to the number of bits per second of central processing capacity that is devoted to the task. So if part of this processing capacity is directed to another task, then the applied force will diminish.

Pashler speculates on the possibility of a neurophysiological explanation of the facts he describes, but notes that the parallel versus serial distinction between the two mechanisms leads, in the classical neurophysiological approach, to the questions of what makes these two mechanisms so different, and what the connection between them is. [p.354-6, 386-7]

After analyzing various possible mechanisms that could cause the central bottleneck, Pashler [p.307-8] says ``the question of why this should be the case is quite puzzling." Thus the fact that this bottleneck, and its basic properties, follow automatically from the same laws that explain the complex empirical evidence in the fields of classical and quantum physics means that the theory has significant explanatory power.

Of course, the fact that this theory seems to work so well does not mean that it is the only theory that can work. But in the past science has been well served by the endeavor of trying to understand various complex high-level processes in ways that all fit together coherently with basic physical theory. The brain is a physio-chemical structure that rests in principle on quantum processes, and the quantum principles lead in a completely natural way to a specified kind of dynamical linkage between the aspects of the mind-brain that are described in psychological and physical terms. All classically described features are accounted for in the quantum description, which however provides also a natural dynamical place for mind whereas classical physics does not.

Quantum theory automatically accounts for all the successes of classical physical theory. So the fact that classical ideas work well in neuroanatomy and for other large scale phenomena is not evidence that classical physics will work in domains where quantum effects ought to come in, such as the migration of calcium ions inside of nerve terminals. The quantum description becomes necessary only when treating subtle dynamical effects, which, however, can have important large scale effects. The effect of mental effort to hold ideas in place longer than classical computations would predict seems to be the most crucial dynamical difference between the classical and quantum models. This effect could eventually become important in neuroscience. I shall discuss that in Chapter 10. But in any case it immediately entails a major revision in the scientific conception of human beings. This all rests on von Neumann's mathematics.

## 9. OTHER INTERPRETATIONS.

Some physicists are dissatisfied with von Neumann's formulation of quantum theory, and have put forth alternative proposals. The origin of their dissatisfaction is the entry of our streams of conscious thoughts into basic physical theory. However, our conscious thoughts are certainly parts of reality, and are, indeed, the very parts of reality whose existence is least in doubt. Every part of reality probably has some effect upon the whole. Hence it would seem not only natural, but also imperative, that the laws of nature should provide a way for mind---for idea-like realities---to influence nature, and, in particular, the flow of events in our brains. Thus the incorporation by quantum theory of mental events into brain dynamics would appear to be an important step in the right direction. Nevertheless, some conservative scientists believe that science should cling to the nineteenth century ideal, which specifies that the workings of brains can be completely described, at least in principle, without considering idea-like realities, which are deemed to be either redundant arrangements of mindless realities, or causally inert bystanders.

In this connection Kathryn Blackmond Laskey of George Mason University wrote:

*I would appreciate your answering a question I have.*

*There is much disagreement in the literature about the reduction process and how it works, including controversy over whether there is any such thing as reduction. I have read numerous statements from physicists that measurement involves inter action of a quantum system with its environment, and is (it is asserted) therefore "nothing but" Schrodinger evolution on a larger system.*

It has, indeed, been sometimes claimed that the interaction with the environment solves the measurement problem. However, the principal protagonists of this notion (e.g., W. Zurek, D. Zeh, & E. Joos) do not, I believe, claim that all of the essentials of that proposal have really been worked out. I have argued [Can. J. Phys. 2002: The basis problem in many-worlds theories, vol. 80, pp.1043-105] that important aspects have *not* been worked out, and that the gaps are

sufficiently serious to block, at the present time, the claim that the Schroedinger equation alone (and this includes the environmental decoherence) is actually sufficient, by itself, to tie the theory to well-defined predictions pertaining to human experiences. Such predictions are required for the theory to be scientifically meaningful, and they are obtained in the von Neumann formulation only by introducing the Process I dynamical interventions, which are explicitly tied to idea-like realities.

The reason, in brief, why an extra dynamical process is needed is this: If the universe has been evolving since the big bang solely under the influence of the Schroedinger equation then every object and every human brain would be by now, due to the uncertainty conditions on the original positions and velocities, represented in quantum theory by an amorphous continuum: the center-point each object would not lie at a particular point, or even be confined to a small region, but would be continuously spread out over a huge region; and, likewise, the state of the brain every observer of this object would be a smeared out conglomeration of many different classical-type brains, one corresponding to each of the allowed center-points in this big region. That is, if a human person were observing an object, whose center-point, as specified by its quantum state, were spread out over a region several meters in diameter, then the state of the brain of that person would have, for each of these different locations, a part, corresponding to the observer's seeing the object in that location. If each of these parts of the brain were accompanied by the corresponding *experience*, then there would exist not just one experience corresponding to seeing the object in just one place, but a *continuous* aggregation of experiences, with one experience for each of the possible locations in the large region. Thus this theory is often called, quite rightly, a "many-minds" interpretation: John Doe evolves into a smeared out continuum of John Doe's each having an experience different from every other one.

In order to extract from quantum theory a set of predictions pertaining to human experiences, and hence to give empirical meaning to the theory, this smeared out collection of different brain structures must be resolved in a very special way into a collection of *discrete* parts, each corresponding to one possible experience. This *discreteness*

*condition* is a technical point, but it constitutes the essential core of the measurement problem. Hence I must explain it!

Evolution according to the Schroedinger equation (Process II) generates in general, as I have just explained, a state of the brain of an observer that is a smeared out continuum of component parts, each corresponding to a different possible experience. One cannot assign a nonzero probability to each one of such a continuum of possibilities, because the total probability would then be infinity, instead of one (unity). However, the mathematical rules of quantum theory have a well-defined way to deal with this situation: they demand that the space of possibilities be divided in a certain very restrictive way into a countable set of alternative possibilities, where a *countable set* is a set that can be *numbered* (i.e., placed in one-to-one correspondence with the integer numbers 1, 2, 3, ...). The need to specify a particular *countable set* of parts is *the essential problem* in the construction of a satisfactory quantum theory. But then the technical problem that the dissenters face is this: How does one specify a satisfactory particular *countable set* of *discrete* possibilities from Process II alone, when Process II is a *continuous* local process that generates a structure that continuously connects components that correspond to very different experiences, and hence must belong to different members of the countable set? The problem is essentially the same as saying that a process generates only a circle generates also some particular point on that circle: an extra property is imputed to a process that lacks that property.

In the Copenhagen formulation of quantum theory this selection of a preferred set of discrete states is achieved by a *choice on the part of the experimenter*. The measuring device, set in a particular place by the experimenter, selects some particular part of the state of the observed system that corresponds to some particular kind of experience. In this simple case the countable set has just two elements, one specified by the projection operator  $P$ , the other specified by the projection operator  $(I-P)$ . In this way the basic problem of specifying a countable set of discrete parts is solved by bringing into the theory *a choice on the part of the experimenter*. Von Neumann solves this discreteness problem in the same way, and gives this selection process the name Process I.

Einstein posed essentially the same problem in a clear way. Suppose a pen that draws a line on a moving scroll is caused to draw a blip when a radio-active decay is detected by some detector. If the only process in nature is Process II, then the state of the scroll will be a blurred out state in which the blip occurs in a continuum of alternative possible locations. Correspondingly, the brain of a person who is observing the scroll will be in a smeared out state containing a continuously connected collection of components, with one component corresponding to each of the possible locations of the blip on the scroll. But how does this smeared out continuously connected state of the brain get divided by Process II alone into distinct components corresponding to different experiences?

A key feature of the orthodox approach is the “empirical fact” that experimenters can have definite thoughts, and that they can therefore place the devices in definite locations. Thus it is the discreteness of the *choice* made by the experimenter that resolves the discreteness problem. But an experimenter represented by a state governed solely by the Schroedinger equation has nothing discrete about him: his brain is a continuous smear with no dynamically defined dividing lines.

The founders of quantum theory (and von Neumann) recognized this basic problem of principle, and in order to resolve it went to a radical and revolutionary extreme: they introduced human experimenters with efficacious free choices into the physical theory. This was a giant break from tradition. But the enormity of the problem demanded drastic measures. Because such powerful thinkers as Wolfgang Pauli and John von Neumann found it necessary to embrace this revolutionary idea, anyone who claims that this unprecedented step was wholly unnecessary certainly needs to carefully explain why. But this has not been done. Rather, the environmental decoherence effect has been taken to be a panacea. However, that well understood effect has no significant impact on the discreteness problem.

The environmental decoherence effect merely reduces the matrices representing macroscopic systems to *near* diagonal form. [Recall that each physical system is represented by a “matrix”  $S(I,I)$ , where  $I$  specifies a location for every “particle” in the classical conception of

the system, and so does  $I'$ . The “diagonal” elements are those for which  $I = I'$ , but the slightly off-diagonal elements remain generally nonzero, and they lock the whole near-diagonal structure together.] The region where  $S(I,I)$  is significantly different from zero remains large, even after the effects of interaction with the environment are taken into account. It is not broken up by the continuous action of Process II into a collection of different, isolated regions that could be associated with different experiences. But then the way in which the countable set of discrete states is singled out evidently depends on something besides Process II, and the quantum state whose evolution it generates. In any case, the way that particular experiences are assigned finite probabilities, given only Process II, needs to be worked out and described in detail by anyone who claims that the Schrodinger evolution alone is sufficient.

Actually, the problem is technically much more difficult than the above brief sketch indicates. The real situation involves a space of an infinite number of dimensions, but the discreteness problem can be illustrated in a simple model having just two dimensions. Take a sheet of paper and put a point on it. (Imagine that your pencil is infinitely sharp, and can draw a true point, and perfectly straight lines of zero width.) Start drawing straight lines out from the point in different directions. With an infinitely sharp pencil you could draw lines in different directions for billions of years, at one line a second, and not come even close to using up the set of all possible directions. However, the rules of quantum theory demand in this two dimensional case that some one particular direction, (together with the one perpendicular to it) be picked out from this continuous infinity of possible directions as preferred to all the others. But how is such an incredibly precise choice determined by this continuous Process II?

This is the famous “basis problem.” which was solved by the founders, and by von Neumann, by invoking the choice on the part of the experimenter. Although bringing in the human experimenter in this special way is certainly very contrary to the ideas of classical physics, the notion that our streams of consciousness play some important dynamical role in the determination of our behavior is not outlandish: it is what almost anyone would naturally expect.

This description of the discreteness problem is rather concise, and perhaps too abstract to really hit home to a non-physicist reader. What is really wrong, you may still ask, with going along with just the Process II alone, and the amorphous continuous state  $S(I,I)$ ? Why is this choice of a discrete basis so essential? Let me explain this in more concrete terms.

If you have just a countable set of states then you could, for example, assign probability  $\frac{1}{2}$  to the first state, probability  $\frac{1}{4}$  to the second state, probability  $\frac{1}{8}$  to the third, and so on, and the total probability will add to one (unity), as a sum of probabilities should. But if  $S(I,I)$  is a continuous function of  $I$ , and there were a distinct experience for each value of  $I$ , and  $S(I,I)$  were non-zero for some value of  $I$ , then  $S(I,I)$  would necessarily be larger than some (perhaps very tiny) non-zero number, say  $e$ , in some finite region. (This follows from the continuousness of  $S(I,I)$ , and the fact that  $S(I,I)$  must be a positive number or zero.) But there is an infinite number of possible values of  $I$  in any finite interval, and if each one represents a real existing different experience, then the total probability for an experience to occur would be at least infinity times  $e$ , or infinity.

The main idea of quantum theory is to use a generalization of the theorem of Pythagoras to resolve this problem. That theorem says that the sum of the squares of the two shorter sides of a right triangle is equal to the square of the longer side. This rule generalizes to a figure in a space of an infinite number of dimensions in the following way: If a displacement of unit length is a sum of a set of displacements *each perpendicular to every other one*, then the sum of the squares of the lengths of these displacements is one (unity). Using this law we can guarantee that probabilities of the different experience possible in any given situation will add to one (unity) if we assert that the different possible experiences correspond to *a set of mutually perpendicular directions in the space of possibilities*. But these preferred directions are an infinitely small fraction of the set of all possibilities. So the main problem in principle in the construction of a satisfactory quantum theory is: How are these special directions in the space of all possibilities singled out from all the others?

The conclusion of the founders, and of von Neumann, and of myself, is that these special directions cannot be selected by Process II alone. Any contrary claim needs to be spelled out in detail.

Kathryn went on to say:

*Bohm and Hiley say this (that there is no collapse or reduction) in describing their hidden variable theory.*

Bohm's pilot-wave model is another attempt to add onto the raw theory an extra process, in order to tie the raw theory to human experiences in a quantitative way.

The main objection to that theory is that, in spite of many years of intensive effort, it has not been generalized to cover relativistic cases involving particle creation and annihilation.

I once asked Bohm how he answered Einstein's charge that his model was "too cheap". He said that he agreed! And notice that the last two chapters of his book with Hiley tries to go beyond this model. David Bohm, like myself, saw the need to deal more adequately with consciousness, and he wrote several papers on the subject. At the present time Hiley is working on ideas that go far beyond the concepts used in the old pilot-wave model. I do not think any physicist actually working in the area would claim that the pilot-wave model exists today in the relativistic domain.

Kathryn continued:

*Others also say this, including people who don't subscribe to the Bohm pilot wave + particle ontology, such as Carver Mead in "Collective Electrodynamics," who gives a fairly well worked-out example of a quantum oscillator jumping an energy level, and how this can be explained by systems that briefly cross phases, exchange energy, then go out of phase again.*

Quantum theory explains very well how information is continuously transferred to measuring devices. But those beautiful descriptions are the *basis* of the measurement problem, not the solution. They do not

explain how some object whose location (as represented by the quantum state) is spread out over meters is experienced as being located close to a point, and with some well defined probability.

Kathryn continues:

*R. Mirman says "Wavefunctions don't collapse, oversimplifications do... Perhaps what collapses is not the statefunction, but common sense... Discontinuity cannot be true, and it is not. But carelessness unfortunately can be true and too often is, and certainly can make discontinuity appear true." He goes on to amplify: "If for example we consider an object striking a screen forming a spot, the statefunction of the system after the formation, the product of that of the struck atom plus all objects attracted to it and the scattered object, is found from the initial one using Schrodinger's equation, and if so found would be seen to vary continuously. In principle it is possible to calculate final (perhaps extremely complicated) statefunctions from initial ones, and the entire transformation from one statefunction to another is completely continuous. Never is there a sudden change or collapse. Any such appearances result from ignoring the (continuous) intermediate stages by regarding these as happening instantaneously."*

Quite true! If process II is the whole story then there never is a sudden change or collapse! That's the problem! The Schroedinger equation generates only continuous changes. But the continuousness of that Process II evolution is closely tied to the fact that in a universe evolving exclusively via the Schroedinger Equation, (i.e., Process II) ever since the big bang, the detector is everywhere, instead of somewhere, and the observer's brain is a smeared out continuum encompassing all possibilities. The continuousness stressed by Mirman is the problem, not the solution.

Once, long ago, I characterized the many-worlds solution as shifting the whole measurement problem onto the mind-brain problem, about which it says nothing. For the theory, to be empirically meaningful it must be tied to probabilistic statements about alternative possible human experiences. But the smeared-out state of the brain does not cleanly separate vectors from other vectors that differ from them by very tiny amounts. But then what principle, involving nothing but the

evolving amorphous state of the universe, can separate the space of brain states into orthogonal subspaces, such as those defined by P and (I-P), associable with different experiences?

I do not claim that this problem has no solution. But Mirman's observation that a world evolving according to the Schroedinger equation alone is evolving continuously does not *solve* the measurement problem: it *creates* the measurement problem. Certainly, Heisenberg and Pauli, and von Neumann, understood very well that a world evolving according to a universally valid Schroedinger equation would evolve continuously. And they also realized that this did not solve the measurement problem. I have absolutely no doubt that von Neumann understood very well also the essential features of environmental decoherence: the basic ideas are all clearly displayed in his work. Yet in order to get an empirically meaningful theory he brought in Process I.

## **10. RAMIFICATIONS IN SCIENCE.**

Scientists are free to choose which concepts they take as basic in their endeavor to describe the structure of human experience. Isaac Newton took the point-like idealizations of our visual experiences of distant planets and small physical objects. This is a highly restrictive choice because it leaves out most types of human experience, such as colors, sounds, pains, efforts, evaluations, etc.

Bohr, Pauli, Heisenberg, and the other founders of quantum theory shook off the inertia the Newtonian tradition and demonstrated the advantages of bringing the observing and acting human agents into basic physical theory. Their formulation is the one used in practical work in physics, and there is little likelihood that this will change in physics. However, in other fields, including neuroscience, psychology, and philosophy of mind, many researchers still use the Newtonian concepts, even though physicists know them to be inadequate in principle in systems that depend sensitively on underlying chemical and ionic processes.

Living systems were explicitly excluded by Bohr from the domain of applicability of Copenhagen quantum theory. That limitation was removed by von Neumann's reformulation. All other contenders are, I

believe, plagued with problems that can be interpreted as stemming from the failure to incorporate into the dynamics a psychological dimension or aspect that adequately ties the mechanical Process II to the psychological aspects of reality. Hence only von Neumann's formulation can, at present, justifiably claim to apply to thinking brains.

The oft-made assertion that the classical approximation is adequate for brain dynamics needs to be justified by calculations based on the more accurate quantum theory. Such calculations have been carried out, and they show just the opposite: they show, as discussed earlier, that quantum effects inside nerve terminals *can have* important macroscopic dynamical consequences. Hence quantum theory certainly needs to be used for a fully adequate treatment of brain processes, and its only currently available and technically adequate form, namely von Neumann quantum theory, injects the mind into the dynamical workings of the brain.

The key practical question is then: Does it make any difference in evolving scientific practice whether or not we use the apparently necessary existence of von Neumann's Process I. or can we simply ignore it?

A first question is: What is current scientific practice, and how is it evolving?

To get a perspective on this question I shall quote from an article that just appeared on a respected electronic forum dealing with the mind-brain problem. The forum is called Psyche-D, and the article is authored by Eddy A. Nahmias of the Department of Philosophy at Florida State University. The paper is entitled "Verbal Reports of the Contents of Consciousness: Reconsidering introspective psychology."

[<http://psyche.cs.monash.edu.au/v8/psyche-8-21-nahmias.html>]

This paper is pertinent because it sketches out, from a philosophical standpoint, the development of psychology from "introspectionism," to "behaviorism," to contemporary "cognitive psychology." The author notes that whereas introspectionism went to the extreme of banning the brain from psychology, and behaviorism went to the opposite

extreme of banning consciousness, cognitive psychology, though strongly biased by its behaviorist roots, does use verbal reports, and does sometimes treat these reports not as mere behavioristic responses, but rather as indicators of properties of existing experiential states. The author suggests that the time is now ripe for a limited rehabilitation, with appropriate care, of some of the methods and goals of introspectionist psychology, though not their views on the nature of mind. He notes that cognitive scientist interested in consciousness “avoid flirting with dualism” and recognize that “denying dualism need not mean denying a role for introspection.” He says that “To approach these questions we should first avoid several potential roadblocks. First, we should not assume that the methodology of introspectionism cannot be separated from its problematic philosophy, such as its inherent dualism ... .”

These words draw attention to a certain incongruity in that approach to the study of the mind-brain problem: while the rhetoric hews closely to the behavioristic philosophy of rejecting that “bete noir”, *duality*, actual practice deals with two kinds of data, those arising from physical measurements of brain process and those arising from verbal reports that are treated as indicators of states of consciousness. Given this duality displayed in both contemporary empirical practice, and the immediate direct theoretical interpretation of verbal reports, what is the rational basis of hanging onto the philosophical rejection of duality?

Daniel Dennett put his finger on the reason. His book “Consciousness Explained” has a chapter “Why Dualism Is Forlorn”, which begins with the words:

“The idea of mind as distinct ...from the brain, composed not of ordinary matter but of some other special kind of stuff is dualism, and it is deservedly in disrepute today. ... The prevailing wisdom, variously expressed and argued for is materialism: there is one sort of stuff, namely matter---the physical stuff of physics, chemistry, and physiology---and the mind is somehow nothing but a physical phenomenon. In short, the mind is the brain.”

Dennett then asks: “What, then, is so wrong with dualism? Why is it in such disfavor?”

He answers:

“A fundamental principle of physics is that any change in the trajectory of a particle is an acceleration requiring the expenditure of energy ...this principle of conservation of energy ... is apparently violated by dualism. This confrontation between standard physics and dualism has been endlessly discussed since Descartes’s own day, and is widely regarded as the inescapable flaw in dualism.”

This argument depends on identifying “standard physics” with nineteenth century physics. But the argument collapses when one goes over to contemporary physics, in which, due the Heisenberg Uncertainty Principle, trajectories of particles are replaced by cloud-like structures, and in which, moreover, consciousness can influence brain activity without violating the laws of physics. Contemporary physical theory allows, and in its von Neumann form entails, an interactive dualism. So there is no good reason to dismiss or rule out the possibility that a useful science of consciousness could be built on the idea that mind and brain are two aspects of reality that are most adequately described in psychological and physical terms, respectively, and that they interact in the way described by contemporary physical theory, namely von Neumann quantum theory.

It may be useful to elaborate on this point within the framework of Nahmias’s sketch of the development of psychology during the twentieth century.

In 1898 the introspectionist E.B. Titchener delineated the proper study of psychology as the conscious mind, defined as “ nothing more than the whole sum of mental processes experienced in a single lifetime.” And: “We must always remember that, within the sphere of psychology, introspection is the final and only court of appeal, that psychological evidence cannot be other than introspective evidence. ”

However, the psychologist William James (1892), who used introspection extensively, but recognized a causal link of consciousness to brain process, lamented that psychology had not developed any laws: “ We do not even know the terms between which the elementary laws would obtain if we had them.”

J.B. Watson, emphasizing the failures of introspection to achieve reliable results, went to the opposite extreme. He began his 1913 behaviorist manifesto with the words: "Psychology as the behaviorist views it is a purely objective experimental branch of natural science. Its theoretical goal is the prediction and control of behavior. Introspection forms no essential part of its methods, nor is the scientific value of its data dependent upon the readiness with which they lend themselves to interpretation in terms of consciousness."

The behaviorist movement made rapid gains and in 1917 H. W. Chase wrote a summary of the years work on "Consciousness and the Unconscious" in which he reports:

"There can be no question that consciousness is rapidly losing its standing as a respectable member of the psychologists vocabulary. Titchener in the preface of his new book says: I have avoided the use of the word 'consciousness.' Experimental psychology has made a serious effort to give it scientific meaning, but the attempt has failed, the word is too slippery, and so is better discarded."

However, behaviorism began to have increasing technical difficulties with verbal reports of conscious experiences. Nahmias stresses that when we use a thermometer to measure the temperature of some system, what is important is not the point to which the Mercury rises: what is important is the property of the system that the position of the indicator reliably reports. Likewise, in verbal reports of conscious experience it is not the sounds themselves that are important: it is the property of the human system that the sounds reliably report.

The technical difficulties with behaviorism continued to mount, but, in Nahmias's words, "It was not until Chomsky's (1959) famous review of Skinner's ... analysis that the tide fully turned against trying to treat language, including reports about human experience, just like any other behavior." But this turning of the tide meant that behaviorism failed precisely at the point at issue: the connection of physical process to conscious process. Yet the pariah status that behaviorism had assigned to dualism continued to persist after the fall of behaviorism, and it still persists today, as the words of Dennett show, and the commentary of Nahmias confirms.

Nahmias goes on to laud cognitive science, with its more inclusive approach of trying to correlate measured brain activity with reports of consciousness. He argues that these reports, at least in some cases, seem to be reports *about something*: they are not just sounds to be interpreted merely as sounds. “They are interpreted as reliable indicators of experiences.” And he goes on to suggest that maybe some of the ideas of the introspectionists can, under special conditions, be useful in developing an idea of a structure of consciousness that could be correlated with the structure of brain activity.

This rehabilitation of consciousness is both reasonable and useful. And it is in line with the twentieth century developments in physics.

Switching to the quantum model has, in principle, important physical ramifications. If Process I exists, and is exploited by living systems in the way I have suggested, via the Quantum Zeno effect, then living systems would tend to be more stable and goal-directed than a classically describable system, or a system evolving solely under the action of the Process II alone, could possibly be. So, at least in principle, Process I has empirical consequences: the questions involved here are scientific one, not just matters of words and viewpoints.

The appearance of behavior explainable by a Quantum Zeno Effect does not imply a necessary incursion into the physical world of some non-physical agent. The simplest way to activate a Quantum Zeno Effect action would be for a higher-level subsystem of the brain to monitor a lower-level subsystem that is more directly connected to motor control. This circumstance emphasizes the fact that von Neumann’s theory brings the mind-driven Process I into brain dynamics, but leaves open the question of what causes the mental choices to be just what they are and not something else.

The brain certainly plays a very important role in those choices. So the inclusion of Process I in the dynamics is not meant to be, and is not, an opening to mysticism. It is an acceptance of a conclusion that arose within science, namely the fact that quantum theory is

compatible with---and in its von Neumann form actually entails---the conclusion that our streams of consciousness are potent contributors to brain dynamics. Since our streams of consciousness are also the basis of all science, it is hardly anti-scientific or mystical to include them in a scientific account of the world.

The existence Process I entails a failure of the local deterministic Process II. This means that within von Neumann quantum theory the classical idea that brain dynamics is controlled basically by a local mechanical process is false, and that any attempt to force our understanding of brain process to fit that mold must fail.

Process I involves non-local operators  $P$ , which specify the brain correlates of psychological events. This suggests that an adequate theory of the activity of a thinking brain ought to be a psycho-physical theory that includes, irreducibly, both the psychologically and physically described realities. One would think that this would be orthodox and main stream view, instead of a fiercely opposed alternative that in Dennett's words "is deservedly in disrepute today."

This dualistic way of constructing mind-brain dynamics is surely far more practical and more likely to succeed than the way ordained by classical physics. That is because it is impossible to get the information needed to specify the initial classical brain conditions with enough precision to make the classical equations predictive in the interesting situations where delicate conscious evaluations play the decisive role in selecting which course of action will be pursued. Thus the classicality requirement imposes a very severe conceptual limitation without achieving any resultant increase in predictive power. Moreover, the quantum uncertainty principle would render the course of brain events indeterminate in principle even if the effects of classical noise could be brought under control.

Once it is appreciated that the local mechanistic classical laws *must fail*, and that the quantum Process I injects the non-local physical correlates of *conscious thoughts* into the dynamics of brain processes, it becomes scientifically reasonable to believe that an adequate theory of brain dynamics should describe mind-brain process in psycho-physical terms rather than insisting that the dynamics be described fundamentally in local mechanistic terms

alone. There is no scientific basis for going either to the extreme of building the basic theory of the mind-brain on brain alone, as the materialist or physicalists demand, or to the extreme of building the theory on mind alone, as the idealists and humanists would have it. Quantum theory provides the basis for a dynamical middle way that includes in a rationally coherent manner both the mental and physical aspects of reality without reducing either one to the other.

## **11. VALUES.**

This book began with the observation that what science says about what you are, and how you are connected to the rest of nature, can affect your values, and hence your life. It can affect also the values and attitudes of everyone responsive to the findings of science, and this includes many influential thinkers, and consequently the social milieu that undergirds your life.

Our focus so far has been upon the twentieth-century revolution in what science says about these matters. That century began with science proclaiming the simple doctrine of a fully mechanical universe; of a universe consisting of tiny realities whose lawfully specified interactions with immediate neighbors fix the entire course of history from primordial initial conditions. Thoughts, ideas, and feelings need never be considered, because the dynamical rules can be stated---and their consequences fully determined---without ever acknowledging the existence of such entities. But that old mechanical picture, however simple and attractive it was, cannot describe the dynamics of human brains. In that system, for reasons spelled out in earlier chapters, quantum effects are important and the only formulation of quantum theory that seems adequate to deal with a thinking brain is the one devised by John von Neumann. This theory, like its classical predecessor, has a causal process that is fully determined by the interactions between tiny neighboring entities. Von Neumann calls this process Process II. However, in the quantum case this mechanism by itself it does not yield a complete physical theory: it is augmented by a second process, called Process I, which injects effects of our thoughts, ideas, and feelings directly into

workings of the brain. The older classical mechanical laws can be seen as an approximation to the quantum laws that systematically excludes all quantum effects. This approximation has the effect of excluding all of the dynamical effects of mind upon brain that quantum theory introduces. The classical laws are therefore blinkered: they systematically cut from view the effects of minds upon the rest of nature, and in particular upon the brains associated with them.

Having explained in earlier chapters these critical developments in science we can turn now to the question of their impact upon human values.

I have already mentioned the question of personal responsibility for one's acts. This concept has been greatly corroded by the classical notion that we are simply the product of our genes and our environment, and hence cannot be responsible for anything we do: that our actions are just automatic consequences of blind local mechanical processes. The notion that a person's mental effort can, to a large degree, control his actions is thus dismissed as an illusion, disproved by "modern science," which purportedly reveals us to be mechanical robots deluded by the absurd belief that such insubstantial and immaterial phantasms as our thoughts could affect the implacable march of the atoms.

There can be no doubt that this notion of the ineffectualness of our minds to control our actions has gained great standing and credibility in our legal, social, intellectual, institutional, and philosophical systems, and that this idea has drawn immense support from the authority of science. But the picture of the human agent that emerges from orthodox quantum theory is much more sophisticated, and not at all in line with the classical idea of a mechanical automaton. The new conception of Man entails the effectiveness, at least in principle, of the action of mind on brain, and, as was discussed in chapter 8, the structure of the effect seems to be in good agreement with both Jamesian psychology and the data from the studies of the psychology of attention. The new physics describes a specific mechanism whereby mental effort can control brain activity, while leaving open, so far, the cause of this feeling of effort. However, this mental effort

controls an effect that is capable in principle of overriding the strongest forces arising from the mechanical side of nature. This development in physics casts serious doubt upon the verdict of nineteenth century science, and rescues both the deliverances intuition, and the notion of personal responsibility based on that intuition.

A second effect pertains to non-locality. I mentioned in connection with Process I the possibility of including within physics the further process, Process III, that actually obliterates from the objective real universe, all but one of the alternative possibilities specified by Process I. According to that scenario, if you see the Geiger counter “fire”, then there is *no* alternative branch of the universe in which the “you that existed before looking at the Geiger counter,” subsequently sees the counter as “not firing.”

In order to focus on Process I, I left open the ontological issue of whether this obliterating Process III, really occurs as an objective physical process, or merely *seems to you* to occur.

Having upset the claim that the causal efficacy of our thoughts is necessarily an illusion, we are led to question the idea that the “collapse” or “reduction” Process III is merely a subjective illusion. Accepting Process III as an objectively real physical process is the simplest way, and perhaps the only unambiguous way, of understanding the probability rules. But the real existence of Process III, would have profound ontological consequences: it would imply that the stream of conscious events that defines you as a thinking entity is instantly connected, causally, to ontologically similar streams of consciousness occurring all over the universe. The argument for this is technical, and is given in an appendix.

This placement of yourself in that network of non-local causal connections gives you an image of yourself that is profoundly different from the idea of yourself that flows from classical physics. The latter portrays you as basically as a pile of dirt, or a vehicle constructed by mindless genes for a purpose they do not know. Those pictures contrast starkly to the quantum image of yourself as a center of creativity that gives form to the universe, in coordination

with a vast array of similar centers with which you are instantaneously connected.

This brings us to the basic issue of self image. What are you? What do you conceive yourself to be? What is the purpose or meaning of your life? How do you go about forming opinions on these matters? Do you simply accept the pronouncements of an “authority,” such a church, or a state, or some social or political group? All of these entities have agendas of their own, and they need to make you, or others, believers of their message. But then where can you find unbiased truths?

Science kneels down in the end only to an authority that is beyond the pettiness of human ambition. It rests, finally, on the stubborn facts of nature, which reveal something about the nature of a reality that supports your being. And these stubborn facts uncovered by the labor of scientists reveal also things about the nature of you yourself as an observer and participant in the unfolding of reality. It tells you things about yourself that are deeper and more secure than the tales created by human beings for human purposes.

Science may not tell you everything you need to know: it is an ongoing enterprise, which may from time to time even issue false claims, as the example of classical physics so amply proves. But it is the result of enormous work by countless investigators, and represents, barring revelation, the most reliable information available to you. And it feeds into most of the other information that you receive because the leading opinion-makers try to espouse views not directly contradicted by the findings of science.

You may have often found it difficult to believe yourself to be what classical physics claimed you to be, namely a blob of protoplasm reacting mechanically to the buffeting of a mindless universe filled with similar blobs, all constructed by certain protein molecules as a consequence of some freakish quirks in the laws of nature. But that bizarre idea, improbable as it might seem, is the picture that is, even today, being drummed incessantly into the heads of us all, including our impressionable children. It is promulgated as the scientific word on high.

This pervasive indoctrination is certainly not devoid of effect. The behavior that this dreary and debasing self-image tends to promote is unquestionably vastly different from the behavior powered by an image of one's self as a center of power in an instantaneously linked network of mindful and potent agents jointly engaged in a struggle to create a world measuring up to possibilities formed by our collective ideals.

The destiny of our species will be determined above all by how we view and understand our potentialities and collective power. Quantum theory delivers, on that score, a message based on empirical evidence that is almost diametrically opposed to the pronouncements of classical physics. Whereas the message of classical physics was that of separation, competition, and mindless mechanism, the message of quantum physics is one of unification, collaborative effects, and mindful process. Given the overriding importance of human ideas upon the fate of man the importance of the shift of the weight of science from the classical concepts to the quantum concepts can scarcely be overstated.